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Remeasuring the HDI by Data Envelopement Analysis

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Contents

Abstract

The measurement of human development has a potentially strong impact on how the development gap is viewed and on the formulation of new policies. Therefore correct and fair measurement is of great importance. In this paper, we develop an algorithm to compute comprehensive differentiation rules suitable for measuring human development. We used models from Data Envelopment Analysis (DEA) literature to compare performance in a multiple output setting. The models were evaluated by empirically re-estimating the human development index (HDI). The most notable advantages of DEA models are that they endogenously construct a non-linearly arranged set of best practice countries and that the weights of each indicator entering the HDI is endogenously determined based on an optimization calculus. These weights are allowed to vary thereby accounting for cross-sectional heterogeneity. While country clusters are identified by their similarity, some interesting outliers can also be singled out using DEA. Such outliers are either best practice frontier countries or countries that are locked in an underdevelopment trap.

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Remeasuring the HDI by Data Envelopment Analysis

Bernhard Mahlberg and Michael Obersteiner

1 Introduction

The experience in development research of the past fifty years has demonstrated that development is possible but not inevitable. While a few countries have succeeded in rapid societal and economic growth, narrowing the gap between themselves and the more advanced countries and bringing millions of their citizens out of poverty, many more countries have actually seen the development gap grow and poverty increase. Human hardship, injustice, environmental degradation, and illiteracy are not measured when countries are benchmarked according to their Gross Domestic Product (GDP) per capita ranking. The GDP indicator does not measure the 'fitness' of a particular country or society as a whole, but rather summarizes the current state of specific activities within a society. It has little to do with measuring and explaining the advancements of human societies. The GDP indicator also has little predictive power, since it only measures present success and not the probability of increasing human welfare in the long-term, which might depend on a society's capacity to adapt to new environments (Brookfield, 2001). Thus, measurements of human development must be rooted deeper in society and include a multiplicity of differentiating indicators.

Development research has come up with new differentiating rules to measure the states of human development. Such new rules allow for improved differentiation between countries taking into account characteristics that are idiosyncratic to specific aspects of human development. Differentiation rules that comprise a composite of indicators, each summarizing a particular aspect of human welfare, allow for a more comprehensive assessment of human development. Establishing such multiple criteria differentiation rules is intimately connected to a discussion of the ethical basis of weighting each aspect that summarizes a facet of human development relative to other aspects. Tremendous scientific, analytical, and political effort has gone into the process of constructing the Human Development Index (HDI) as a simple, comprehensive, and fair differentiation rule of human welfare.

The human development index has been rather successful in serving as an alternative measure of development that supplements GDP (Sen, 1999a). Based on three distinct components — indicators of longevity, education, and income per head — it is not exclusively focused on economic opulence, which GDP is. Within the limits of these three components, the HDI has served to substantially broaden the empirical attention that the assessment of development processes receives. However, the HDI, which is

inescapably a crude index, must not be seen as anything other than an introductory move in getting people interested in the rich collection of information that is present in many international multidisciplinary databases, many of which are geographically explicit. The HDI today is something like a flagship indicator comparing the *conditio humana* in all nations of the world.

As already mentioned, the HDI is a rather crude measure and is, as the inventor Mahbub-ul-Haq claims, 'of the same level of vulgarity as GDP — just one number — but a measure that is not as blind to social aspects of human lives as GDP is". Mahbub-ul-Haq hoped that not only would the HDI be something of an improvement on — or at least a helpful supplement to — GDP, but also that it would serve to broaden public interest in the other variables that are at least equally important to achieve higher levels of human development. Klein (2001) sees the HDI and the other development indices that are tabulated in the United Nations Development Programme's Human Development Report as excellent information sources for further work of economists engaged in development economics. Based on its original intention, the crude index should speak loud and clear and receive intelligent attention. The HDI should serve as a vehicle through which the complex task of transforming societies along a newly adapted development strategy can occur.

In this light a correct measurement of the HDI is of great importance. The HDI has been criticized several times since it was invented and first published. From the academic literature two branches of criticism can be identified. The first addresses the choice of indicators that the Index contains. The tenor is that the HDI fails to measure the real condition of life in a country because important aspects of development are not taken into account such as, for example, the environmental situation, distribution of income, or political stability. As a consequence, the results can lead to an improper assessment of the status of development or the tendencies of development during the last few years. The recently published work of Dasgupta (2001) has added a new point of view to the critical literature. In his opinion, the consideration of what he calls 'a country's productive base' is omitted. This is a country's stock of physical and human capital as well as the natural capital of soil, forests, biodiversity, etc. Taking these parameters into account the assessment of the word development is completely different. The second branch of literature addresses methodological issues. Several alternative computation approaches have been suggested. A good overview of this literature has been given in the recent work of Neumayer (2001).

This paper is in line with the second branch. Our goal is to improve the measurement of the HDI and to make the measurement more scientific. We acknowledge and honor the effort that has been put into reducing the complexity of measuring human development by using three indicators, namely longevity, education, and income per head. This is a major achievement and will not be further scrutinized in this paper; we will, though, build on this achievement. We feel, however, the need to add some value to the measurement of the HDI by improving the computation of the index given the pre-selected set of indicators. The currently used algorithm for computing the HDI implicitly assumes that countries shall linearly be sorted according to their summarized performance of three indicators, each of which is assigned a fixed and predetermined weight. We argue that human development should (1) be benchmarked using a non-linear model and empirical information of best practice countries, and (2) the indicator

weights should be directly derived from the original data set itself and vary across the cross-section allowing for heterogeneity. We, therefore, propose a different method of computing the HDI using Data Envelopment Analysis (DEA), which is capable of accounting for these problems.

2 Data

We used the same indicators as those in the World Development Report that is published annually by the United Nations Development Program (UNDP), which are used to compute the Human Development Index (HDI). The four indices that are summarized in the HDI can be derived from the following three categories: longevity, knowledge, and decent standard of living. Longevity is measured in years by life expectancy at birth ranging from 25 to 85 years. For measuring knowledge, two variables have been chosen, namely adult literacy and the combined gross primary, secondary, and tertiary enrolment ratio. Adult literacy is defined as the number of people who can read and write in relation to the whole population of each country. The combined gross enrollment ratio is defined by the following formula:

combined gross enrollment ratio =
gross enrollment ratio primary education * 7/17 +
gross enrollment ratio secondary education * 5/17 +
gross enrollment ratio tertiary education * 5/17.

Both variables of knowledge are measured in percent. The real GDP per capita serves as the standard of living measure. It is given in US Dollar purchasing power parity, ranging from USD 100 to USD 40,000. Table 1: summarizes the statistics of the variables used. A complete listing of the data can be found in the Appendix.

Table 1: Indicators used in the Human Development Index (HDI), 1998.

	Mean	Standard Deviation	Minimum	Maximum
Longevity:				
Life expectancy at birth [years]	65.6	10.4	79.9	34.7
Knowledge:				
Adult literacy rate [%]	78.41	22.05	99.0	13.6
Combined enrolment ratio [%]	63.25	18.67	100.0	15.0
Decent standard of living:				
Adjusted per capita income [PPP$]	6950	7285	34004	355

Note: Total sample size is 174.
Source: Own computations on the basis of data from UNDP (1998).

Our computations are based on data published by the Human Development Report Office (UNDP, 1998). The HDI as well as our DEA driven indices are computed for a large sample of 174 countries from the five continents, ranging from very high to very low human development.

3 Method

3.1 Human Development Index (HDI)[1]

The HDI is based on three indicators: longevity measured by life expectancy at birth; educational attainment measured by a combination of adult literacy (two-thirds weight) and a combined gross primary, secondary, and tertiary enrolment ratio (one-third weight); and standard of living measured by real GDP per capita (PPP$).

To construct the index, fixed minimum and maximum values have been established for each of these indicators:

- Life expectancy at birth: 25 years and 85 years.
- Adult literacy rate: 0% and 100%.
- Combined cross enrolment ratio: 0% and 100%.
- Real GDP per capita (PPP$): $100 and $40,000 (PPP$).

Individual indices can be computed for any component of the HDI according to the general formula:

$$\text{Index} = \frac{\text{actual value - minimum value}}{\text{maximum value - minimum value}} .$$

If, for example, life expectancy at birth in a particular country is 65 years, the index of life expectancy for this country would be:

$$\text{Life expectancy} = \frac{65 - 25}{85 - 25} = \frac{40}{60} = 0.667 .$$

The construction of the income index is slightly more complex. Income is treated by using the following formula:

$$\text{Income index} = \frac{\log(\text{actual income}) - \log(\text{minimum income})}{\log(\text{maximum income}) - \log(\text{minimum income})} .$$

[1] For details see UNDP (2000: 269).

3.1.1 Aggregation

The aggregation is done by the following process:

In the first step, the adult literacy index and the combined cross enrolment index is aggregated to the education attainment index.

Education attainment index =
2/3 * Adult literacy index +
1/3 * combined cross enrolment index.

In the second step, a simple average of the life expectancy index, the educational attainment index, and the adjusted real GDP per capita (PPP$) index is computed. The sum of three indices is divided by 3.

With the normalization of the values of the variables that make up the HDI, its value ranges from 0 to 1. The HDI value of a country shows the distance that it has already moved towards the maximum possible value of 1 and also allows comparisons with other countries. The difference between the value achieved by a country and the maximum possible value shows the country's shortfall and indicates how far the country has to go.

3.2 Data Envelopment Analysis (DEA)

3.2.1 Standard model

The basic problems when expressing the economic performance in one single indicator are first, to aggregate a number of non-commensurate performance indicators (such as level of national income per capita, life expectancy, etc.) to one single performance measure. And second, to establish a benchmark that can be used for comparing the performance of the countries in the sample.

In most studies, a weighted sum is calculated to aggregate the individual indicators. A good example is the HDI described above. The weights are chosen by the researcher and reflect his preferences. The results of this calculation are influenced by these weights. The assessed countries are ranked with respect to their performance scores. An alternative, suggested by Lovell and Pastor (1994) and Lovell (1995), is the DEA, which is a non-parametric approach that uses a linear programming technique. The DEA defines the best practice frontier that serves as a benchmark and minimizes the relative distance to this benchmark. This distance is interpreted as the economic performance of the countries in the sample. It is equivalent to the weighted sum. The weights are calculated by the DEA within the optimization process.

Farrell (1957) introduced the concept of the best practice frontier, which delineates the technological limits of what a country can achieve with a given level of resources. The solid line in Figure 1: shows the best practice frontier computed by DEA in a situation in which two indicators are combined into one single performance index. Each dot in the diagram (A to D) stands for the performance of a country in the sample. The DEA constructs an envelope for the observed indicator combinations of all countries in the

sample under the constraint that all well-performing countries support the envelope. The frontier is called best practice frontier and allows us to classify countries into well-performing units if they are at the frontier and into worse performing units if they lie below. A worse performing country could either augment the indicator number one or number two, or even both. The indicator of performance is then given by the relative distance between the actual observed performance and the nearest benchmark.

In Figure 1, three countries (A, B, and C) support the DEA — best practice frontier and are classified as best performing. Country D lies below the best practice frontier and is identified as worse performing. As a performance indicator we used the radial distance measure developed by Farrell (1957). It is defined as the ratio of the distance between the origin and the projected point of the examined country at the frontier divided by the distance between the origin and the actual observed point. For example, the performance of country D is $0D^T/0D$. The performance score for the best performing countries is 1 and for the worse performing countries it is larger than 1.

The case shown in Figure 1 is the aggregation of two indicators with the aid of an index-maximizing DEA. An index-maximizing DEA seeks to compute economic performance as a proportional augmentation in all indicators.[2] The index-maximizing approach is applied if the scores of all indicators are preferred to be as high as possible (e.g., GDP, literacy rate, etc.).[3]

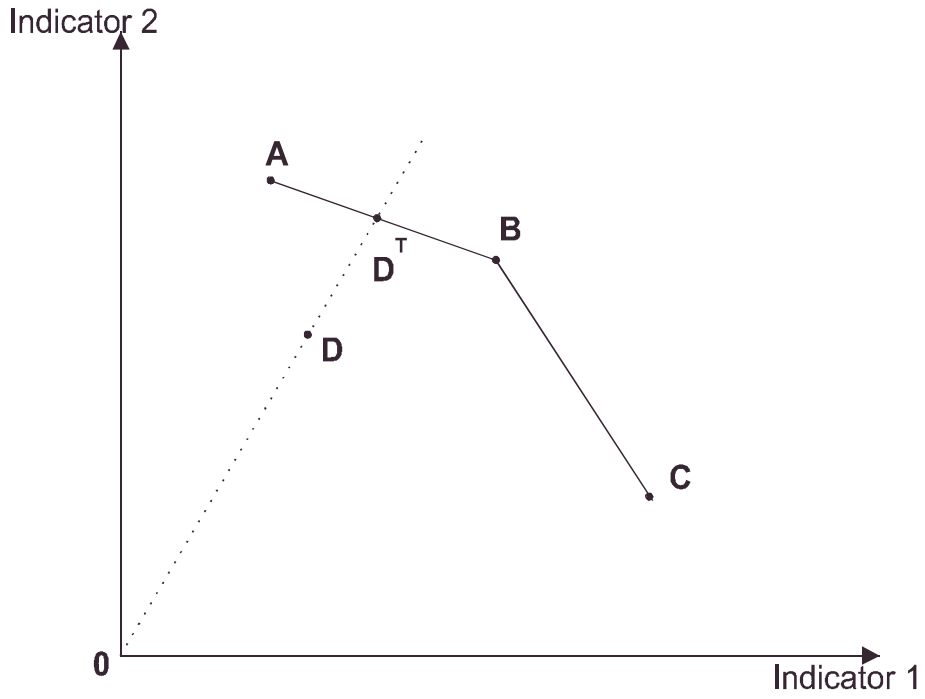

Figure 1: Determining the best performing countries with normal DEA.

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[2] Another term in literature for this kind of DEA is "output-oriented DEA" (see Coelli *et al*., 1998: 137).

[3] A different way to aggregate indicators is to apply an index-minimizing DEA. This approach is adopted if the scores are preferred to be as low as possible (interest rate, inflation, etc.). In literature, this kind of DEA is usually termed as "input-oriented DEA" (see Coelli *et al*., 1998: 137).

The computation of the envelope and the development index can be reduced to a linear program for each individual country in which the following optimization problem is solved:[4]

$$\min \sum_i v_i x_{i0} = Z_0$$

$$\text{s.t.} \quad \sum_r \mu_j y_{r0} = 1$$

$$-\sum_r \mu_r y_{rj} + \sum_i v_i x_{ij} \geq 0 \qquad \textit{(for each of the N countries)}$$

$$v_i \geq \varepsilon, \qquad \mu_r \geq \varepsilon$$

where

Z_0 ... performance score,

ε ... non-archimedean variable ($\varepsilon = 10^{-8}$),[5]

x_{ij} ... i-th resource of the j-th country, $i = 1,..., m$, m ... number of resources, $m = 1$,

y_{rj} ... r-th indicator of the j-th country, $r = 1,..., s$, s ... number of indicators, $s = 4$,

$j = 1,..., N$, N ... number of countries, $N = 174$,

v_i ... weight of the i-th resource,

μ_r ... weight of the r-th indicator.

This procedure computes the performance score Z_0 of a single country that is equal to the weighted sum of the four indicators and must be repeated for each country in the sample. Because we combine the four indicators of the HDI, the resource side consists of the unity vector. The model computes the weights so that the country under instigation is ranked as best as possible. Every weight of individual indicators can lie between 0 and 1 and the sum of all weights must be equal to 1. The weights can differ from country to country in contrast to the standard definition of the HDI, where the weights are equal for all countries.

Figure 1 also shows one particular weakness of the DEA. This model has the characteristic to diagnose any country supporting the frontier to be equally well performing even if it is superior with respect to one indicator but performs poorly with respect to all the others (e.g., C). This weakness is the well-known boundary problem. For such a country, the DEA computes a high weight to the indicator where the country is superior and a low weight to all the other indicators. In an extreme case, the DEA selects a weight of one for that indicator and a weight of zero to the others. Only this indicator is taken into account for computing the performance index. This characteristic makes the results of the basic model implausible.

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4 This linear program was developed by Charnes *et al*. (1978).

5 The issues of the appropriate specification of the non-archimedean variable are discussed in Ali (1994:78).

In order to differentiate between different benchmark countries, a ranking procedure could be used, for example, the extended DEA model developed by Andersen and Petersen (1993). Using this technique would not fundamentally improve the results because the main characteristics of the model would not change. Therefore, the flexibility in the selection of weights must be limited to solve the boundary-problem. This is done by applying a DEA model with weight restrictions.

3.3 Model with Weight Restrictions

The type of restriction we used is termed in the literature as "Type I Assurance Regions".[6] This type of restriction is illustrated by restriction A in the following linear program:

$$\min \sum_i \nu_i x_{i0} = Z_0$$

$$\text{s.t.} \qquad \sum_r \mu_j y_{r0} = 1$$

$$-\sum_r \mu_r y_{rj} + \sum_i \nu_i x_{ij} \geq 0 \qquad \textit{(for each of the N countries)}$$

$$\alpha \leq \frac{\mu_r}{\mu_{r+1}} \leq \beta \qquad \textit{restriction A}$$

$$\nu_i \geq \varepsilon, \qquad \mu_j \geq \varepsilon$$

where

Z_O ... performance score,
ε ... non-archimedean variable ($\varepsilon = 10^{-8}$),
x_{ij} ... i-th resource of the j-th country, $i = 1,..., m$, m ... number of resources, $m = 1$,
y_{rj} ... r-th indicator of the j-th country, $r = 1,..., s$, s ... number of indicators, $s = 4$,
$j = 1,..., N$, N ... number of countries, $N = 174$,
ν_i ... weight of the i-th resource,
μ_r .. weight of the r-th indicator,
α, β ... lower and upper bound of weight relation.

The flexibility in selecting the weight is limited by setting the positive lower and upper bounds of the relative weights of all four indicators (restriction A). This limitation ensures that no weight can be zero or one. We computed the DEA models with three different intervals of lower and upper bounds [α, β], namely [0.001, 1000], [0.01, 100] and [0.1, 10]. This linear program also computes the development score Z_0 of a single country and must be repeated for each country in the sample. The resource side consists of the unity vector.

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6 Allen *et al*. (1997) gives a good overview about DEA models with weight restrictions.

4 Results

4.1 Introductory Remarks

Basically, in order to measure the performance of countries, we used different indicators divided into the following three categories: longevity, knowledge, and decent standard of living. Applying the basic DEA model developed by Charnes *et al*. (1978) and one DEA model with weight restrictions developed by Allen *et al*. (1997), we computed two performance indices for each country in the sample. Both DEA models are index-maximizing models.

The scores of both DEA-models are, per definition, 1 or larger and a value of 1 is assigned to the best performing country. By transforming the scores of the DEA to the domain between zero and one, we make the DEA scores comparable to the values of the HDI. The transformation is done by inverting the DEA scores.[7] The values of the transformed indicators lie between 0 and 1, as in the values of the HDI. The domain of the HDI, as published in the Human Development Report, is between 0 and 1, but even the best performing country does not achieve the highest possible value. To ensure comparability with the DEA values we normalized the HDI. To the highest developed country a value of 1 is assigned and to all relatively less developed countries a value of less than 1.

All three indices are interpreted in the same way. The values of both indices show the distance that a country has already moved towards the maximum possible value of 1 and allows comparisons with other countries. The difference between the value achieved by a country and the maximum possible value of 1 shows the country's shortfall and indicates how far the country has to go.

4.2 Human Development Index (HDI)

Table 2 shows the transformed HDI scores and the ranks of the top ten countries. The highest developed country is Canada followed by France, Norway, and the USA. Norway and the USA are equally ranked as well as Iceland and France. This shows that the HDI does not discriminate completely and thus some countries are ranked equally.

The weights are determined externally by the designer of the index and are equal for all countries. Therefore, the construction of the index is inflexible because it does not take into account the particular situation of the country shown by the figures.

[7] This is a standard procedure for transforming DEA scores. For a description and discussion, see Coelli *et al*. (1998: 134–160).

Table 2: Scores and ranking of the Human Development Index.

Country	Score	Rank
Canada	1.000	1
France	0.985	2
Norway	0.982	**3**
USA	0.982	**3**
Iceland	0.981	**5**
Finland	0.981	**5**
Netherlands	0.980	7
Japan	0.979	8
New Zealand	0.978	9
Sweden	0.975	10

Note: Total sample size is 174.
Source: Transformed values based on UNDP (1998).

4.3 Basic DEA Model

By using DEA we compute endogenous weights and, in this way, we make the HDI more scientific and overcome the inflexibility of the original design. The DEA approach is more flexible because it computes weights, which depend on the data.

Table 3 reports the development score computed by a basic DEA model of a collection of countries. All of the countries listed are ranked first.[8] One of the main characteristics of the DEA is that it chooses the weights so that each country has the highest possible development score. This is the reason why the DEA computes, for countries that have the highest values of 99 percent in the adult literacy and only relatively poor values in the other indicators, a weight of one for this indicator and a weight of zero for all the others.[9] This means that the DEA only takes into account the adult literacy for these countries. It turns out that for most of the countries ranked at the top, the adult literacy rate is 99 percent. From a total of 174 countries, 32 are ranked at the top, 27 of which the DEA has computed a weight of 1 for adult literacy.

8 The results for all of the countries can be found in the Appendix.

9 The data we used for the computation are reported in the Appendix.

Table 3: Scores, ranking, and weights of the basic DEA model.

Country	Scores	Ranking	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP
Norway	1	**1**	0	1	0	0
Poland	1	**1**	0	1	0	0
Russian Federation	1	**1**	0	1	0	0
Slovakia	1	**1**	0	1	0	0
Sweden	1	**1**	0	1	0	0
Switzerland	1	**1**	0	1	0	0
Tajikistan	1	**1**	0	1	0	0
United Kingdom	1	**1**	0	1	0	0
USA	1	**1**	0	0	0.56	0.44
Uzbekistan	1	**1**	0	1	0	0

Note: Total sample size is 174.
Source: Own computations.

4.4 DEA with Weight Restrictions

To improve the discriminating power of the DEA and obtain a realistic and plausible ranking, we impose restrictions on the DEA weight. The relative weight of indicator *i* to the weight of indicator *j* is restricted to between 0.01 and 100. In this way, we solve the problem of zero weights completely. None of the indicators are excluded from the analysis and almost none of the countries are ranked equally.

As can be seen from Table 4, no country, among the top 10, is equally ranked with another. The ranking is therefore unambiguous for most countries. Luxembourg is the most developed country followed by Brunei Darussalam and the USA. The following positions are occupied by Switzerland, Canada, and Norway. This ranking is quite plausible.[10]

We have also tried wider and narrower intervals between lower and upper bounds (0.1 and 10 as well as 0.001 and 1000). We found that the wider the interval the similar are the results with the outcomes of the basic DEA-model and so the problems of basic DEA model appears again. The narrower the interval the less the room for maneuver for the DEA-procedure to select weights and thus the more the weights are predetermined by the researcher. As a consequence of using wider intervals more then one country is ranked on the same position. With the lower bound of 0.01 and the upper bound of 100 we steered a middle course between too strong predetermination and too large flexibility for the DEA.

[10] The complete ranking can be found in the Appendix.

Table 4: Scores, ranking, and weights of the DEA model with weight restrictions.

Country	Score	Ranking	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Luxembourg	1	**1**	0.002	0.225	0.001	0.772
Brunei Darussalam	0.972	**2**	0.163	0.002	0.160	0.675
USA	0.944	**3**	0.141	0.183	0.177	0.499
Switzerland	0.876	**4**	0.156	0.197	0.151	0.496
Canada	0.868	**5**	0.159	0.199	0.201	0.441
Norway	0.860	**6**	0.157	0.201	0.187	0.455
Denmark	0.843	**7**	0.156	0.205	0.184	0.455
France	0.835	**8**	0.165	0.207	0.186	0.443
Belgium	0.833	**9**	0.161	0.207	0.180	0.451
Japan	0.831	**10**	0.168	0.208	0.164	0.461

Note: Total sample size is 174.
Source: Own computations.

4.5 Comparison of Both DEA Indices with the HDI

In this section we compare the results of the original HDI with that of the two DEA models. First, we compare the results of the HDI with the results of the basic DEA model and the DEA model with the weight restrictions by considering descriptive statistics and the histograms. Then we show the similarities and differences with the aid of correlation coefficients. Finally, we work out the similarities and differences by considering the rankings in detail.

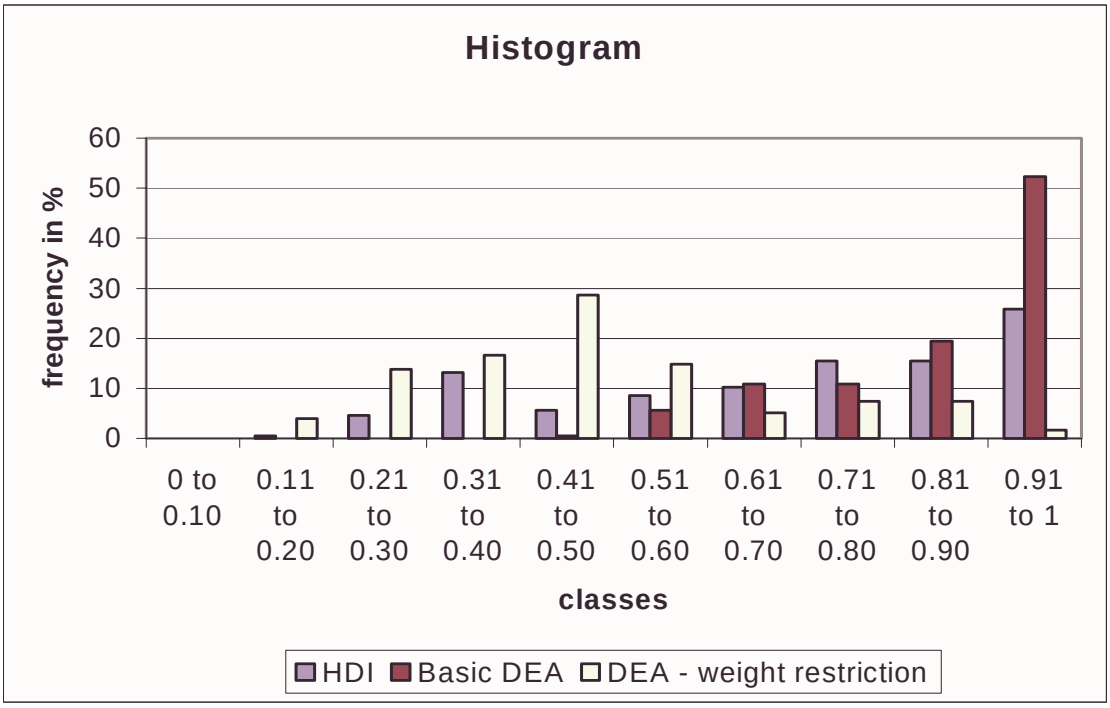
The comparison of the values computed by the basic DEA model with the HDI values reveals that the mean of the DEA scores is clearly higher than the values of the HDI. On average, the scores of the DEA model with weight restrictions are the smallest (Table 5). The variation of the scores from the basic DEA model measured by the standard deviation is lower than that of the HDI, whereas the variation of the scores from the DEA with weight restrictions lies in-between. The difference between the highest and the lowest score is the smallest for the basic DEA scores and the highest for scores computed by the DEA with weight restrictions. With respect to the basic DEA index, the countries are nearest to the benchmark country on average.

The histogram of the indices (Figure 2) reveals the following. The index values of the basic DEA model are distributed very unequally. The distribution reaches its maximum between 0.91 and 1. The majority (52 percent or the values of 91 countries) of the values lie in this class. Less than 20 percent of the scores can be found in each of the other classes. None of the basic DEA scores lie below 0.51.

Table 5: Descriptive statistics, HDI scores, and the DEA results.

	HDI	Basic DEA	DEA with weight restrictions
Mean	0.654	0.852	0.446
Median	0.729	0.909	0.465
Standard deviation	0.228	0.139	0.189
Maximum	1	1	1
Minimum	0.193	0.434	0.148

Note: Total sample size is 174.



Note: Total sample size is 174.

Figure 2: Histogram of the index values.

The HDI is also distributed unequally but to a lesser extent. It has its frequency maximum in the class between 0.91 and 1, however the distribution appears much flatter. Around 26 percent of the scores lie within this class. The rest of the scores are fairly well distributed to the other classes. The variation of the HDI values is higher than the DEA values. According to the HDI fewer countries lie within the upper two classes with values equal to or higher than 0.81, than according to the basic DEA model.

In contrast to the distributions of the HDI and the basic DEA the scores of the DEA with weight restrictions appears to be almost symmetrical and resembles the shape of the normal distribution. It has its maximum frequency in the class from 0.41 to 0.50. Twenty-nine percent of the development scores (of 50 countries) are in this class. Almost the same number of countries has scores above or below this class. Only nine countries or two percent have scores above 0.81.

The upper part of Table 6 shows the correlation of the index values computed by the HDI and the two DEA models with each other and with the four indicators (life expectancy, adult literacy, enrolment ratio, and GDP per capita), whereas the lower part presents the correlation of the rankings of the three indices with each other and with the ranking of the four indicators.

Table 6: Correlation between the components and the indices.

	Life Expectancy	**Adult literacy**	**Enrolment ratio**	**GDP per capita**	**HDI**	**Basic DEA**	**DEA with weight restrictions**
Correlation coefficient							
HDI	**0.929**	0.847	0.856	0.734	1		
Basic DEA model	0.909	**0.917**	0.844	0.565	0.893	1	
DEA with weight restrictions	0.837	0.758	0.794	**0.936**	**0.901**	0.798	1
Spearman rank correlation coefficient							
HDI	0.933	0.791	0.809	**0.958**	1		
Basic DEA model	0.825	**0.959**	0.772	0.716	0.831	1	
DEA with weight restrictions	0.917	0.812	0.820	**0.949**	**0.982**	0.855	1

Note: Total sample size is 174.

The correlation coefficients of the indices with the indicators reveal that any index is strongly correlated with only one particular indicator. None of the indices is equally related with all of the indicators. The values of the HDI are strongly connected with life expectancy, whereas the values of the basic DEA model are highly correlated with adult literacy and the values of the DEA with weight restrictions are related mostly with the GDP per capita. The correlations of the values computed by the three models reveal that the outcomes of the DEA with weight restrictions are most similar with the HDI.

The correlation coefficients of the rankings are quite similar to the correlation coefficients of the values. The only remarkable difference is that the rankings of the HDI are more strongly connected to GDP per capita than to life expectancy. Apart from this difference, the picture is the same as before. The rankings of the scores from the basic DEA model are strongly related to those of adult literacy, and the rankings from the DEA with weight restrictions are strongly correlated with that of GDP per capita. The rankings from the DEA model with weight restriction are strongly correlated to those of the HDI.

Resulting from the fact that the HDI scores are strongly correlated with those of the DEA with weight restrictions as well as the rankings of these models are strongly related together, we conclude that the design of the HDI is quite good. It provides a realistic and plausible picture of the real status of developments and the weights fit quite well to the data.

Table 7 provides deeper insight into the differences between the three indices and shows the top and bottom five countries of the three rankings. It turns out that all of the top five countries of the HDI ranking and all top five countries of the ranking based on DEA with weight restrictions are also ranked in the first position according to the basic DEA. A total of 32 countries are ranked at the top by the basic DEA model. These facts show that the discriminating power of the basic DEA model is unsatisfactory. The comparison of the ranking according to the HDI with the DEA with weight restrictions shows that two countries (Canada and the USA) are within the top five of both rankings and, thus, these countries are within the top five in all three rankings. The other three countries of the top five are different. Further similarities between the HDI and the ranking of the DEA model with weight restrictions can be found if we consider the bottom five countries. Four of the five countries are included in this group with respect to both techniques but in a slightly different order. The bottom five of the ranking, based on the basic DEA, includes completely different countries (with the exception of Sierra Leone). This is a further sign that the basic DEA does not improve the HDI computation.

Table 7: Top and bottom five countries.

	HDI	**Basic DEA Model**[3]	**DEA with weight restrictions**
Top five	Canada	Canada	Luxembourg
	France	France	Brunei Darussalam
	Norway [1]	Norway	USA
	USA [1]	USA	Switzerland
	Finland [2]	Finland	Canada
	Iceland [2]		
Bottom five	Burundi	Gambia	Ethiopia
	Mali	Guinea	Sierra Leone
	Burkina Faso	Burundi	Mali
	Niger	Guinea-Bissau	Burkina Faso
	Sierra Leone	Sierra Leone	Niger

Note: Total sample size is 174.
[1] Norway and the USA are equally ranked third.
[2] Finland and Iceland are equally ranked fifth.
[3] These 5 and a further 27 countries are ranked at the top because their performance score is equal to one. Due to space restrictions only 5 are listed.

If we consider the complete ranking, we conclude that the distinction between the rankings of the basic DEA model and the HDI is bigger than that of the DEA with weight restrictions and the HDI. The mean differences as well as the largest positive and negative differences between the HDI and the basic DEA are bigger than between the HDI and the DEA with weight restrictions.

The reason for the differences between the rankings lies in the weights used in the aggregation of the four variables. In the HDI the designer of the index predetermines the weights, whereas in DEA the linear program selects the weights. So, they are a result of an optimization process. These DEA weights may be objectively correct, whereas the

weights of the HDI could be wrong and lead to distortion of the ranking and of the conclusions.

4.6 Discussion of the Difference Between the HDI and DEA Measurements

Despite the strong correlation between the HDI and the measure of the DEA with weight restrictions of human development (correlation of values is at least 0.89 and rank correlation is at least 0.83), there are also some notable differences between the two measurements. In particular, the upper part of the ranking order changed considerably. This is striking taking into account that differing combinations of the same set of three indicators can entirely explain the difference between the two measurements. We can, thus, conclude that the choice of algorithm used to compute the compound index significantly affects the country ranking. Our results show that there are two main reasons for these differences:

(1) Linearity of the benchmark; and
(2) Subjectivity of weights attached to each indicator of the compound index.

The HDI is an index that is comprised of linear combinations of individual indicators. Changes in indicators are always linear and change the compound index according to their respective weight. Contrarily, DEA is a non-linear model as a number of best performing countries form the efficient frontier. The benchmark frontier is a piece-wise linear approximation of a non-linear best practice 'technology' (see Figure 1) and is constructed in such a way that it envelopes the observations of the input-output relation as tight as possible. This property in part explains why the development gap between OECD countries and developing countries is smaller than measured by the HDI. Likewise, the standard deviations are much smaller in the DEA estimation compared to the HDI measurement.

More important, however, is the assumption made by the HDI that a more or less impartial analyst or group of analysts are capable of determining the weights of the individual indicators entering the index. This is a strong assumption and biases with respect to this arbitrariness should be eliminated as much as possible since such weights can be politically rather sensitive and are prone to intentional manipulations. In DEA the algorithm 'endogenously' determines the weights. In the optimization procedure, shadow values (prices) are calculated based on the structure of the data. In this way, the assumption that optimization (maximization of the total output-input ratio) is appropriate to analyze the data set at hand substitutes subjective judgment. DEA weights are constructed so that they not only account for indicator weights that are free of judgment, but also account for cross-sectional heterogeneity. While judgment on weighting the various indicators entering the compound index always involves unsolvable discussions on ethical issues, ignorance of the cross-sectional heterogeneity and non-linearity in the benchmarks would lead to a situation where apples are compared to pears. Furthermore, it can be expected that with an increasing number of indicators for the construction of more comprehensive indices the differences between the two approaches will increase. Since there is a tendency that indices are becoming

increasingly more comprehensive, the problems discussed above will become increasingly prevalent.

It can be concluded that the algorithm chosen to compute the HDI depends on the decision whether the HDI should reflect a country's distance to some theoretical benchmark of best practice or should be more data driven and the distance measurement should be endogenously determined. In the latter case, the empirical data in the form of a collection of all the countries determine best practice. The distance measurement between best practice countries and less benchmark countries is determined based on endogenous weights reflecting the structure of the data. These weights are allowed to vary across the cross-section taking into account the heterogeneity of country clusters of different states of development.

5 Conclusion

The measurement and analysis of development by multiple criteria has the potential to reformulate development policies. Development policies improve from the analysis of less successful countries and examples of best or better practice. The correct measurement of development, as illustrated by the HDI in this paper, is therefore of great importance. A broader view of development is based on the multiplicity of differentiation rules. First, it provides a more thorough basis for evaluating the state of the *conditio humana*. Employing more comprehensive measurements enhances the intrinsic relevance of lives and puts less emphasis on measurements of financial opulence (World Bank, 1996).

Second, a more comprehensive measurement of development implicitly leads to broader goals and policies being targeted. Broader goals make policies more consistent, complete, and comprehensive (Stiglitz, 1998a, b). Broader goals are necessary in a world where building blocks of the system are interconnected, for example, changes in education contribute to enhancing freedom, technology, conscious consumer behavior, to name just a few. By focusing on the interconnection and simultaneity, it takes us well beyond the narrow perspective of seeing each indicator in isolation. We live in a world of many institutions involving economic and political markets and by using broader strategies we have to determine how they can supplement and strengthen each other, rather than reduce their effectiveness (North, 2001). Sen (1999b) sees the supportive role of the state as central in enhancing the effective freedom of individuals, for example, in providing public education, health care, social safety nets, good macroeconomic policies and in safeguarding industrial competition and epidemiological and ecological sustainability.

In this paper we aimed at a dual goal. First, strengthening the discussion of multiple differentiation rules measuring human development thereby acknowledging the need for more consistent and comprehensive policies of human development. And second, we propose an alternative algorithm for a more correct computation of the HDI. In applying DEA to the indicators that enter the HDI, the actual measurement of human development becomes scientifically more sound.

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Appendix

Table 8: Normalized HDI scores and data.

	HDI value	Rank	Life expectancy	Adult literacy	Enrolment ratio	GDP per capita
Canada	1	1	79.1	99	100	21916
France	0.985	2	78.7	99	89	21176
Norway	0.982	3	77.6	99	92	22427
USA	0.982	3	76.4	99	96	26977
Iceland	0.981	5	79.2	99	83	21064
Finland	0.981	5	76.4	99	97	18547
Netherlands	0.980	7	77.5	99	91	19876
Japan	0.979	8	79.9	99	78	21930
New Zealand	0.978	9	76.6	99	94	17267
Sweden	0.975	10	78.4	99	82	19297
Spain	0.974	11	77.7	97.1	90	14789
Belgium	0.972	12	76.9	99	86	21548
Austria	0.972	12	76.7	99	87	21322
United Kingdom	0.971	14	76.8	99	86	19302
Australia	0.971	14	78.2	99	79	19632
Switzerland	0.969	16	78.2	99	76	24881
Ireland	0.969	16	76.4	99	88	17590
Denmark	0.967	18	75.3	99	89	21983
Germany	0.964	19	76.4	99	81	20370
Greece	0.963	20	77.9	96.7	82	11636
Italy	0.960	21	78	98.1	73	20174
Israel	0.951	22	77.5	95	75	16699
Cyprus	0.951	22	77.2	94	79	13379
Barbados	0.947	24	76	97.4	77	11306
Hong Kong, China	0.947	24	79	92.2	67	22950
Luxembourg	0.938	26	76.1	99	58	34004
Malta	0.936	27	76.5	91	76	13316
Singapore	0.933	28	77.1	91.1	68	22604
Antigua and Barbuda	0.932	29	75	95	76	9131
Korea, Rep. of	0.931	30	71.7	98	83	11594
Chile	0.930	31	75.1	95.2	73	9930
Bahamas	0.930	31	73.2	98.2	72	15738
Portugal	0.929	33	74.8	89.6	81	12674
Costa Rica	0.926	34	76.6	94.8	69	5969
Brunei Darussalam	0.926	34	75.1	88.2	74	31165
Argentina	0.925	36	72.6	96.2	79	8498
Slovenia	0.924	37	73.2	96	74	10594
Uruguay	0.922	38	72.7	97.3	76	6854
Czech Republic	0.921	39	72.4	99	70	9775
Trinidad and Tobago	0.917	40	73.1	97.9	65	9437
Dominica	0.916	41	73	94	77	6424
Slovakia	0.911	42	70.9	99	72	7320
Bahrain	0.908	43	72.2	85.2	84	16751
Fiji	0.905	44	72.1	91.6	78	6159
Panama	0.904	45	73.4	90.8	72	6258

	HDI value	Rank	Life expectancy	Adult literacy	Enrolment ratio	GDP per capita
Venezuela	0.896	46	72.3	91.1	67	8090
Hungary	0.893	47	68.9	99	67	6793
United Arab Emirates	0.891	48	74.4	79.2	69	18008
Mexico	0.891	48	72.1	89.6	67	6769
Saint Kitts and Nevis	0.890	50	69	90	78	10150
Grenada	0.886	51	72	98	78	5425
Poland	0.886	51	71.1	99	79	5442
Colombia	0.885	53	70.3	91.3	69	6347
Kuwait	0.883	54	75.4	78.6	58	23848
Saint Vincent	0.880	55	72	82	78	5969
Seychelles	0.880	55	72	88	61	7697
Qatar	0.875	57	71.1	79.4	71	19772
Saint Lucia	0.874	58	71	82	74	6530
Thailand	0.873	59	69.5	93.8	55	7742
Malaysia	0.869	60	71.4	83.5	61	9572
Mauritius	0.868	61	70.9	82.9	61	13294
Brazil	0.843	62	66.6	83.3	72	5928
Belize	0.841	63	74.2	70	74	5623
Libyan Arab Jamahiriya	0.840	64	64.3	76.2	90	6309
Suriname	0.829	65	70.9	93	71	4862
Lebanon	0.829	65	69.3	92.4	75	4977
Bulgaria	0.822	67	71.2	98	66	4604
Belarus	0.816	68	69.3	97.9	80	4398
Turkey	0.815	69	68.5	82.3	60	5516
Saudi Arabia	0.810	70	70.7	63	57	8516
Oman	0.803	71	70.3	59	60	9383
Russian Federation	0.801	72	65.5	99	78	4531
Ecuador	0.799	73	69.5	90.1	71	4602
Romania	0.799	73	69.6	98	62	4431
Korea, Dem. People's Rep. of	0.798	75	71.6	95	75	4058
Croatia	0.791	76	71.6	98	67	3972
Estonia	0.790	77	69.2	99	72	4062
Iran, Islamic Rep. of	0.790	77	68.5	69	67	5480
Lithuania	0.781	79	70.2	99	70	3843
Macedonia, FYR	0.780	80	71.9	94	60	4058
Syrian Arab Republic	0.780	80	68.1	70.8	62	5374
Algeria	0.777	82	68.1	61.6	66	5618
Tunisia	0.775	83	68.7	66.7	69	5261
Jamaica	0.766	84	74.1	85	67	3801
Cuba	0.759	85	75.7	95.7	66	3100
Peru	0.759	85	67.7	88.7	79	3940
Jordan	0.759	85	68.9	86.6	66	4187
Dominican Republic	0.750	88	70.3	82.1	73	3923
South Africa	0.747	89	64.1	81.8	81	4334
Sri Lanka	0.746	90	72.5	90.2	67	3408
Paraguay	0.736	91	69.1	92.1	63	3583
Latvia	0.733	92	68	99	67	3273
Kazakhstan	0.724	93	67.5	99	73	3037

	HDI value	Rank	Life expectancy	Adult literacy	Enrolment ratio	GDP per capita
Samoa (Western)	0.723	94	68.4	98	74	2948
Maldives	0.711	95	63.3	93.2	71	3540
Indonesia	0.707	96	64	83.8	62	3971
Botswana	0.706	97	51.7	69.8	71	5611
Philippines	0.705	98	67.4	94.6	80	2762
Armenia	0.702	99	70.9	98.8	78	2208
Guyana	0.698	100	63.5	98.1	64	3205
Mongolia	0.697	101	64.8	82.9	53	3916
Ukraine	0.693	102	68.5	98	76	2361
Turkmenistan	0.688	103	64.9	98	90	2345
Uzbekistan	0.686	104	67.5	99	73	2376
Albania	0.683	105	70.6	85	59	2853
China	0.677	106	69.2	81.5	64	2935
Namibia	0.671	107	55.8	76	83	4054
Georgia	0.659	108	73.2	99	69	1389
Kyrgyzstan	0.659	108	67.9	97	73	1927
Azerbaijan	0.649	110	71.1	96.3	72	1463
Guatemala	0.641	111	66.1	65	46	3682
Egypt	0.638	112	64.8	51.4	69	3829
Moldova, Rep. of	0.635	113	67.8	98.9	67	1547
El Salvador	0.629	114	69.4	71.5	58	2610
Swaziland	0.622	115	58.8	76.7	77	2954
Bolivia	0.618	116	60.5	83.1	69	2617
Cape Verde	0.616	117	65.7	71.6	64	2612
Tajikistan	0.599	118	66.9	99	69	943
Honduras	0.597	119	68.8	72.7	60	1977
Gabon	0.592	120	54.5	63.2	60	3766
Sâo Tomé and Principe	0.586	121	69	75	57	1744
Vietnam	0.583	122	66.4	93.7	55	1236
Solomon Islands	0.583	122	71.1	62	47	2230
Vanuatu	0.582	124	66.3	64	52	2507
Morocco	0.580	125	65.7	43.7	48	3477
Nicaragua	0.570	126	67.5	65.7	64	1837
Iraq	0.560	127	58.5	58	52	3170
Congo	0.541	128	51.2	74.9	68	2554
Papua New Guinea	0.528	129	56.8	72.2	37	2500
Zimbabwe	0.528	129	48.9	85.1	69	2135
Myanmar	0.501	131	58.9	83.1	48	1130
Cameroon	0.501	131	55.3	63.4	45	2355
Ghana	0.493	133	57	64.5	44	2032
Lesotho	0.489	134	58.1	71.3	56	1290
Equatorial Guinea	0.484	135	49	78.5	64	1712
Lao People’s Dem. Rep.	0.484	135	52.2	56.6	50	2571
Kenya	0.482	137	53.8	78.1	52	1438
Pakistan	0.472	138	62.8	37.8	41	2209
India	0.470	139	61.6	52	55	1422
Cambodia	0.440	140	52.9	65	62	1110
Comoros	0.428	141	56.5	57.3	39	1317

	HDI value	Rank	Life expectancy	Adult literacy	Enrolment ratio	GDP per capita
Nigeria	0.407	142	51.4	57.1	49	1270
Dem. Rep. of the Congo	0.399	143	52.4	77.3	41	355
Togo	0.396	144	50.5	51.7	60	1167
Benin	0.394	145	54.4	37	38	1800
Zambia	0.394	145	42.7	78.2	52	986
Bangladesh	0.386	147	56.9	38.1	37	1382
Côte d'Ivoire	0.383	148	51.8	40.1	38	1731
Mauritania	0.376	149	52.5	37.7	38	1622
Tanzania, U. Rep. of	0.373	150	50.6	67.8	33	636
Yemen	0.371	151	56.7	38	49	856
Nepal	0.366	152	55.9	27.5	56	1145
Madagascar	0.363	153	57.6	45.8	31	673
Central African Republic	0.361	154	48.4	60	27	1092
Bhutan	0.361	154	52	42.2	31	1382
Angola	0.358	156	47.4	42	30	1839
Sudan	0.357	157	52.2	46.1	32	1110
Senegal	0.356	158	50.3	33.1	33	1815
Haiti	0.354	159	54.6	45	29	917
Uganda	0.354	159	40.5	61.8	38	1483
Malawi	0.348	161	41	56.4	76	773
Djibouti	0.338	162	49.2	46.2	20	1300
Chad	0.331	163	47.2	48.1	27	1172
Guinea-Bissau	0.307	164	43.4	54.9	29	811
Gambia	0.303	165	46	38.6	39	948
Mozambique	0.293	166	46.3	40.1	25	959
Guinea	0.289	167	45.5	35.9	25	1139
Eritrea	0.286	168	50.2	25	29	983
Ethiopia	0.263	169	48.7	35.5	20	455
Burundi	0.251	170	44.5	35.3	23	637
Mali	0.246	171	47	31	18	565
Burkina Faso	0.228	172	46.3	19.2	19	784
Niger	0.216	173	47.5	13.6	15	765
Sierra Leone	0.193	174	34.7	31.4	30	625

Source: UNDP (1998).

Table 9: Basic DEA results (ranks, scores transformed, weights).

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Australia	1	1	0	1	0	0
Austria	1	1	0	1	0	0
Belgium	1	1	0	1	0	0
Brunei Darussalam	1	1	0	0	0.31	0.69
Canada	1	1	0.72	0	0.27	0.01
Czech Republic	1	1	0	1	0	0
Denmark	1	1	0	1	0	0
Estonia	1	1	0	1	0	0
Finland	1	1	0	1	0	0
France	1	1	0	1	0	0
Georgia	1	1	0	1	0	0
Germany	1	1	0	1	0	0
Hungary	1	1	0	1	0	0
Iceland	1	1	0	1	0	0
Ireland	1	1	0	1	0	0
Japan	1	1	0.97	0	0	0.03
Kazakhstan	1	1	0	1	0	0
Latvia	1	1	0	1	0	0
Lithuania	1	1	0	1	0	0
Luxembourg	1	1	0	0.53	0	0.47
Netherlands	1	1	0	1	0	0
New Zealand	1	1	0	1	0	0
Norway	1	1	0	1	0	0
Poland	1	1	0	1	0	0
Russian Federation	1	1	0	1	0	0
Slovakia	1	1	0	1	0	0
Sweden	1	1	0	1	0	0
Switzerland	1	1	0	1	0	0
Tajikistan	1	1	0	1	0	0
United Kingdom	1	1	0	1	0	0
USA	1	1	0	0	0.56	0.44
Uzbekistan	1	1	0	1	0	0
Moldova, Rep. of	0.999	33	0	1	0	0
Armenia	0.998	34	0	1	0	0
Hong Kong, China	0.993	35	0.92	0	0	0.08
Bahamas	0.992	36	0	1	0	0
Italy	0.991	37	0	1	0	0
Guyana	0.991	37	0	1	0	0
Korea, Rep. of	0.990	39	0	1	0	0
Grenada	0.990	39	0	1	0	0
Bulgaria	0.990	39	0	1	0	0
Turkmenistan	0.990	39	0	1	0	0
Croatia	0.990	39	0	1	0	0
Romania	0.990	39	0	1	0	0
Samoa (Western)	0.990	39	0	1	0	0
Ukraine	0.990	39	0	1	0	0

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Trinidad and Tobago	0.989	47	0	1	0	0
Belarus	0.989	47	0	1	0	0
Barbados	0.984	49	0	1	0	0
Uruguay	0.983	50	0	1	0	0
Spain	0.981	51	0	1	0	0
Kyrgyzstan	0.980	52	0	1	0	0
Greece	0.978	53	0.96	0	0.04	0
Azerbaijan	0.973	54	0	1	0	0
Argentina	0.972	55	0	1	0	0
Singapore	0.970	56	0.92	0	0	0.08
Israel	0.970	57	1	0	0	0
Slovenia	0.970	58	0	1	0	0
Cyprus	0.968	59	0.96	0	0.04	0
Cuba	0.967	60	0	1	0	0
Chile	0.962	61	0	1	0	0
Antigua and Barbuda	0.960	62	0	1	0	0
Korea, Dem. People’s Rep. of	0.960	62	0	1	0	0
Costa Rica	0.959	64	1	0	0	0
Malta	0.958	65	0.97	0	0.03	0
Philippines	0.956	66	0	1	0	0
Kuwait	0.955	67	0.91	0	0	0.09
Dominica	0.949	68	0	1	0	0
Macedonia, FYR	0.949	68	0	1	0	0
Thailand	0.948	70	0	1	0	0
Vietnam	0.946	71	0	1	0	0
Maldives	0.941	72	0	1	0	0
Portugal	0.940	73	0.96	0	0.04	0
Suriname	0.939	74	0	1	0	0
Lebanon	0.933	75	0	1	0	0
United Arab Emirates	0.931	76	1	0	0	0
Paraguay	0.930	77	0	1	0	0
Belize	0.929	78	0.97	0	0.03	0
Jamaica	0.927	79	1	0	0	0
Fiji	0.925	80	0	1	0	0
Colombia	0.922	81	0	1	0	0
Venezuela	0.920	82	0	1	0	0
Panama	0.919	83	0.97	0	0.03	0
Sri Lanka	0.911	84	0	1	0	0
Ecuador	0.910	85	0	1	0	0
Bahrain	0.910	86	0.96	0	0.04	0
Saint Kitts and Nevis	0.909	87	0	1	0	0
Mexico	0.905	88	0	1	0	0
Saint Vincent	0.904	89	0.96	0	0.04	0
Seychelles	0.901	90	1	0	0	0
Libyan Arab Jamahiriya	0.900	91	0	0	1	0
Peru	0.896	92	0	1	0	0
Malaysia	0.894	93	1	0	0	0
Qatar	0.892	94	0.88	0	0.03	0.09

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Saint Lucia	0.891	95	0.96	0	0.04	0
Solomon Islands	0.890	96	1	0	0	0
Mauritius	0.887	97	1	0	0	0
Saudi Arabia	0.885	98	1	0	0	0
Albania	0.884	99	1	0	0	0
Dominican Republic	0.882	100	0.96	0	0.04	0
Oman	0.880	101	1	0	0	0
Jordan	0.875	102	0	1	0	0
El Salvador	0.869	103	1	0	0	0
China	0.866	104	1	0	0	0
Sâo Tomé and Principe	0.864	105	1	0	0	0
Honduras	0.861	106	1	0	0	0
Tunisia	0.861	107	0.96	0	0.04	0
Zimbabwe	0.860	108	0	1	0	0
Iran, Islamic Rep. of	0.857	109	0.97	0	0.03	0
Turkey	0.857	110	1	0	0	0
Syrian Arab Republic	0.852	111	1	0	0	0
Algeria	0.852	111	1	0	0	0
Indonesia	0.846	113	0	1	0	0
Nicaragua	0.845	114	1	0	0	0
Brazil	0.841	115	0	1	0	0
Bolivia	0.839	116	0	1	0	0
Myanmar	0.839	116	0	1	0	0
Mongolia	0.837	118	0	1	0	0
Namibia	0.830	119	0	0	1	0
Vanuatu	0.830	120	1	0	0	0
Guatemala	0.827	121	1	0	0	0
South Africa	0.826	122	0	1	0	0
Cape Verde	0.822	123	1	0	0	0
Morocco	0.822	123	1	0	0	0
Egypt	0.814	125	0.96	0	0.04	0
Equatorial Guinea	0.793	126	0	1	0	0
Zambia	0.790	127	0	1	0	0
Kenya	0.789	128	0	1	0	0
Pakistan	0.786	129	1	0	0	0
Dem. Rep. of the Congo	0.781	130	0	1	0	0
Swaziland	0.775	131	0	1	0	0
India	0.771	132	1	0	0	0
Malawi	0.760	133	0	0	1	0
Congo	0.757	134	0	1	0	0
Iraq	0.732	135	1	0	0	0
Papua New Guinea	0.729	136	0	1	0	0
Lesotho	0.727	137	1	0	0	0
Madagascar	0.721	138	1	0	0	0
Ghana	0.713	139	1	0	0	0
Bangladesh	0.712	140	1	0	0	0
Botswana	0.710	141	0	0	1	0
Yemen	0.710	142	1	0	0	0

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Comoros	0.707	143	1	0	0	0
Nepal	0.700	144	0.96	0	0.04	0
Cameroon	0.692	145	1	0	0	0
Gabon	0.685	146	0.96	0	0.04	0
Tanzania, U. Rep. of	0.685	147	0	1	0	0
Haiti	0.683	148	1	0	0	0
Benin	0.681	149	1	0	0	0
Cambodia	0.667	150	0.96	0	0.04	0
Mauritania	0.657	151	1	0	0	0
Lao People's Dem. Rep.	0.653	152	1	0	0	0
Sudan	0.653	152	1	0	0	0
Bhutan	0.651	154	1	0	0	0
Côte d'Ivoire	0.648	155	1	0	0	0
Nigeria	0.643	156	1	0	0	0
Togo	0.637	157	0.96	0	0.04	0
Senegal	0.630	158	1	0	0	0
Eritrea	0.628	159	1	0	0	0
Uganda	0.624	160	0	1	0	0
Djibouti	0.616	161	1	0	0	0
Ethiopia	0.609	162	1	0	0	0
Central African Republic	0.606	163	0	1	0	0
Niger	0.594	164	1	0	0	0
Angola	0.593	165	1	0	0	0
Chad	0.591	166	1	0	0	0
Mali	0.588	167	1	0	0	0
Mozambique	0.579	168	1	0	0	0
Burkina Faso	0.579	168	1	0	0	0
Gambia	0.576	170	1	0	0	0
Guinea	0.569	171	1	0	0	0
Burundi	0.557	172	1	0	0	0
Guinea-Bissau	0.555	173	0	1	0	0
Sierra Leone	0.434	174	1	0	0	0

Source: Own computations based on UNDP (1998).

Table 10: Results of the DEA model with weight restrictions (ranks, scores transformed, weights).

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Luxembourg	1	1	0.002	0.225	0.001	0.772
Brunei Darussalam	0.972	2	0.163	0.002	0.160	0.675
USA	0.944	3	0.141	0.183	0.177	0.499
Switzerland	0.876	4	0.156	0.197	0.151	0.496
Canada	0.868	5	0.159	0.199	0.201	0.441
Norway	0.860	6	0.157	0.201	0.187	0.455
Denmark	0.843	7	0.156	0.205	0.184	0.455
France	0.835	8	0.165	0.207	0.186	0.443
Belgium	0.833	9	0.161	0.207	0.180	0.451
Japan	0.831	10	0.168	0.208	0.164	0.461
Austria	0.830	11	0.161	0.208	0.183	0.448
Iceland	0.823	12	0.168	0.210	0.176	0.446
Hong Kong, China	0.816	13	0.169	0.197	0.143	0.491
Netherlands	0.814	14	0.166	0.212	0.195	0.426
Singapore	0.807	15	0.167	0.197	0.147	0.489
Germany	0.803	16	0.166	0.215	0.176	0.443
Finland	0.799	17	0.167	0.216	0.212	0.405
United Kingdom	0.794	18	0.169	0.218	0.189	0.424
Australia	0.790	19	0.173	0.219	0.175	0.434
Sweden	0.789	20	0.173	0.219	0.181	0.427
Italy	0.787	21	0.173	0.218	0.162	0.448
Kuwait	0.786	22	0.167	0.175	0.129	0.529
New Zealand	0.772	23	0.173	0.224	0.213	0.390
Ireland	0.766	24	0.174	0.225	0.200	0.400
Qatar	0.731	25	0.170	0.189	0.169	0.472
Israel	0.723	26	0.187	0.229	0.181	0.403
Spain	0.720	27	0.188	0.235	0.218	0.358
Bahrain	0.713	28	0.177	0.208	0.205	0.410
United Arab Emirates	0.703	29	0.185	0.197	0.171	0.447
Bahamas	0.699	30	0.183	0.245	0.180	0.393
Cyprus	0.670	31	0.201	0.245	0.206	0.348
Malta	0.657	32	0.203	0.242	0.202	0.354
Greece	0.651	33	0.209	0.259	0.220	0.312
Portugal	0.649	34	0.201	0.241	0.218	0.341
Korea, Rep. of	0.643	35	0.195	0.266	0.225	0.315
Barbados	0.634	36	0.209	0.268	0.212	0.311
Slovenia	0.609	37	0.210	0.275	0.212	0.303
Mauritius	0.607	38	0.204	0.238	0.175	0.382
Chile	0.598	39	0.219	0.278	0.213	0.290
Czech Republic	0.592	40	0.214	0.292	0.206	0.288
Saint Kitts and Nevis	0.591	41	0.204	0.266	0.230	0.300
Antigua and Barbuda	0.589	42	0.222	0.282	0.225	0.271
Argentina	0.581	43	0.218	0.289	0.237	0.255
Trinidad and Tobago	0.576	44	0.221	0.296	0.197	0.286
Slovakia	0.550	45	0.225	0.314	0.229	0.232

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Uruguay	0.549	46	0.231	0.309	0.242	0.218
Malaysia	0.544	47	0.229	0.268	0.196	0.307
Venezuela	0.543	48	0.232	0.293	0.215	0.260
Dominica	0.538	49	0.237	0.305	0.250	0.208
Poland	0.530	50	0.234	0.326	0.260	0.179
Fiji	0.529	51	0.238	0.302	0.257	0.203
Hungary	0.528	52	0.228	0.327	0.221	0.224
Grenada	0.527	53	0.238	0.324	0.258	0.180
Costa Rica	0.524	54	0.255	0.316	0.230	0.199
Panama	0.521	55	0.246	0.304	0.241	0.210
Seychelles	0.520	56	0.242	0.295	0.205	0.258
Mexico	0.517	57	0.243	0.302	0.226	0.228
Thailand	0.516	58	0.235	0.317	0.186	0.262
Colombia	0.513	59	0.239	0.311	0.235	0.216
Libyan Arab Jamahiriya	0.512	60	0.219	0.260	0.307	0.215
Saint Lucia	0.510	61	0.243	0.281	0.253	0.223
Saint Vincent	0.509	62	0.247	0.281	0.267	0.205
Belarus	0.508	63	0.238	0.336	0.275	0.151
Russian Federation	0.502	64	0.228	0.344	0.271	0.157
Lebanon	0.500	65	0.242	0.323	0.262	0.174
Suriname	0.495	66	0.250	0.328	0.250	0.172
Oman	0.494	67	0.248	0.208	0.212	0.331
Korea, Dem. People's Rep. of	0.492	68	0.254	0.337	0.266	0.144
Bulgaria	0.491	69	0.253	0.349	0.235	0.164
Brazil	0.491	70	0.237	0.296	0.256	0.211
Estonia	0.490	71	0.246	0.353	0.256	0.145
Lithuania	0.484	72	0.253	0.357	0.252	0.138
Ecuador	0.483	73	0.251	0.326	0.257	0.166
Turkmenistan	0.482	74	0.235	0.355	0.326	0.085
Croatia	0.482	75	0.259	0.355	0.243	0.144
Saudi Arabia	0.481	76	0.256	0.228	0.207	0.309
Peru	0.479	77	0.246	0.323	0.288	0.143
Belize	0.479	78	0.270	0.255	0.270	0.205
Romania	0.478	79	0.254	0.358	0.226	0.162
South Africa	0.471	80	0.237	0.303	0.300	0.160
Samoa (Western)	0.471	81	0.253	0.363	0.274	0.109
Kazakhstan	0.471	82	0.250	0.367	0.271	0.113
Armenia	0.471	83	0.263	0.366	0.289	0.082
Philippines	0.470	84	0.250	0.351	0.297	0.102
Cuba	0.468	85	0.282	0.357	0.246	0.116
Latvia	0.465	86	0.255	0.371	0.251	0.123
Macedonia, FYR	0.465	87	0.270	0.353	0.225	0.152
Ukraine	0.464	88	0.257	0.368	0.286	0.089
Turkey	0.464	89	0.258	0.309	0.226	0.207
Dominican Republic	0.462	90	0.266	0.310	0.276	0.148
Jamaica	0.461	91	0.281	0.322	0.254	0.144
Sri Lanka	0.460	92	0.275	0.342	0.254	0.129
Jordan	0.460	93	0.262	0.329	0.251	0.159

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Uzbekistan	0.459	94	0.256	0.376	0.277	0.090
Maldives	0.459	95	0.241	0.355	0.270	0.135
Paraguay	0.454	96	0.266	0.354	0.242	0.138
Iran, Islamic Rep. of	0.452	97	0.264	0.266	0.258	0.211
Guyana	0.450	98	0.247	0.381	0.248	0.124
Kyrgyzstan	0.449	99	0.264	0.377	0.284	0.075
Tunisia	0.448	100	0.267	0.260	0.269	0.205
Namibia	0.446	101	0.219	0.298	0.325	0.159
Georgia	0.445	102	0.287	0.388	0.271	0.055
Syrian Arab Republic	0.444	103	0.267	0.278	0.244	0.211
Azerbaijan	0.443	104	0.280	0.379	0.283	0.058
Algeria	0.439	105	0.270	0.245	0.262	0.223
Indonesia	0.435	106	0.257	0.336	0.249	0.159
Moldova, Rep. of	0.435	107	0.272	0.397	0.269	0.062
Botswana	0.434	108	0.208	0.281	0.286	0.226
Tajikistan	0.426	109	0.274	0.405	0.282	0.039
China	0.426	110	0.284	0.334	0.262	0.120
Albania	0.424	111	0.290	0.350	0.243	0.117
Swaziland	0.422	112	0.243	0.317	0.318	0.122
Mongolia	0.418	113	0.270	0.346	0.221	0.163
Bolivia	0.417	114	0.253	0.348	0.289	0.110
Vietnam	0.397	115	0.292	0.412	0.242	0.054
Cape Verde	0.397	116	0.289	0.315	0.281	0.115
El Salvador	0.393	117	0.308	0.318	0.258	0.116
Zimbabwe	0.391	118	0.218	0.379	0.308	0.095
Egypt	0.390	119	0.290	0.230	0.309	0.171
Honduras	0.386	120	0.311	0.329	0.271	0.089
Congo	0.383	121	0.233	0.341	0.310	0.116
Sâo Tomé and Principe	0.381	122	0.316	0.343	0.261	0.080
Nicaragua	0.376	123	0.313	0.305	0.297	0.085
Gabon	0.376	124	0.253	0.294	0.279	0.175
Guatemala	0.373	125	0.309	0.304	0.215	0.172
Equatorial Guinea	0.364	126	0.235	0.376	0.307	0.082
Vanuatu	0.362	127	0.320	0.309	0.251	0.121
Solomon Islands	0.353	128	0.351	0.306	0.232	0.110
Myanmar	0.351	129	0.293	0.413	0.239	0.056
Iraq	0.349	130	0.292	0.290	0.260	0.158
Lesotho	0.346	131	0.293	0.360	0.282	0.065
Kenya	0.346	132	0.271	0.394	0.262	0.073
Morocco	0.335	133	0.342	0.227	0.250	0.181
Papua New Guinea	0.333	134	0.297	0.378	0.194	0.131
Cambodia	0.333	134	0.277	0.340	0.325	0.058
Cameroon	0.327	136	0.295	0.339	0.240	0.126
Ghana	0.324	137	0.307	0.347	0.237	0.109
Lao People''s Dem. Rep.	0.322	138	0.283	0.307	0.271	0.139
India	0.319	139	0.337	0.284	0.301	0.078
Zambia	0.319	140	0.234	0.428	0.285	0.054
Malawi	0.316	141	0.226	0.311	0.420	0.043

	Index value	Rank	Weight of life expectancy	Weight of adult literacy	Weight of enrolment rate	Weight of GDP per capita
Dem. Rep. of the Congo	0.304	142	0.301	0.444	0.235	0.020
Togo	0.303	143	0.290	0.297	0.345	0.067
Nigeria	0.297	144	0.302	0.336	0.288	0.075
Comoros	0.290	145	0.340	0.345	0.235	0.079
Pakistan	0.286	146	0.384	0.231	0.251	0.135
Tanzania, U. Rep. of	0.275	147	0.321	0.430	0.209	0.040
Uganda	0.271	148	0.261	0.398	0.245	0.096
Yemen	0.266	149	0.372	0.250	0.322	0.056
Nepal	0.263	150	0.371	0.182	0.371	0.076
Benin	0.257	151	0.369	0.251	0.258	0.122
Côte d'Ivoire	0.257	152	0.352	0.272	0.258	0.118
Central African Republic	0.255	153	0.331	0.410	0.185	0.075
Bangladesh	0.254	154	0.390	0.261	0.254	0.095
Mauritania	0.252	155	0.364	0.261	0.263	0.112
Sudan	0.247	156	0.369	0.326	0.226	0.079
Madagascar	0.246	157	0.408	0.325	0.220	0.048
Bhutan	0.243	158	0.374	0.304	0.223	0.099
Angola	0.240	159	0.344	0.305	0.218	0.134
Haiti	0.240	160	0.396	0.327	0.211	0.067
Guinea-Bissau	0.236	161	0.321	0.405	0.214	0.060
Senegal	0.235	162	0.374	0.246	0.245	0.135
Chad	0.234	163	0.352	0.359	0.202	0.087
Gambia	0.232	164	0.346	0.290	0.293	0.071
Djibouti	0.224	165	0.383	0.360	0.156	0.101
Mozambique	0.211	166	0.383	0.331	0.207	0.079
Guinea	0.206	167	0.386	0.305	0.212	0.097
Eritrea	0.199	168	0.440	0.219	0.254	0.086
Burundi	0.190	169	0.408	0.323	0.211	0.058
Ethiopia	0.190	170	0.448	0.326	0.184	0.042
Sierra Leone	0.179	171	0.339	0.307	0.293	0.061
Mali	0.177	172	0.462	0.305	0.177	0.056
Burkina Faso	0.161	173	0.501	0.208	0.206	0.085
Niger	0.148	174	0.676	0.002	0.213	0.109

Source: Own computations based on UNDP (1998).