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The Sensitivity of the Human Development Index to Assumptions about Income

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ABSTRACT

The Human Development Index (HDI) aims to present a more robust picture of a country's development status than that suggested by national income per capita. The HDI aggregates dimension indices based on transformed measures for the core values of health, education, and income per capita. Assumptions are made regarding the upper and lower bounds used to re-scale each core value into its dimension index, as well as the functional form used to create the HDI. The treatment of income in the HDI's construction suggests incompatibilities with its underlying capability theory, which stresses the importance of individuals' abilities to make their own consumption and life choices. We examine the currently formulated HDI, as well as two influential proposed alternatives which generalize the aggregation functions of the pre-2010 HDI formulation and the current HDI, in light of recent empirical research into the relationship between well-being and income. We use underlying data for 2016, a representative year, to examine distributional changes as well as specific country rankings. We find that the income bounds used to calculate the income dimension index in the HDI should be changed. We also suggest that the three aggregation formulations, along with prominent descriptions of the assumptions and consequent implications of each approach, should be disseminated for policymakers and the public to consider.

KEYWORDS

Capabilities approach; Human Development Index; measurement of human development; income satiation

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1. Introduction

Introduced in the UNDP's 1990 Human Development Report (HDR) and based on work by Nobel prize winning economist and philosopher Amartya Sen and economist Mahboub ul Haq, the Human Development Index (HDI) was conceived of as an alternative to the use of a country's income per capita as a measure of development. This work was based on the beliefs of Sen, ul Haq and others that development economists had focused too heavily on the promotion of economic growth and were over-emphasizing the relationship between income per capita and societal wellbeing. Critics emphasized that by excluding non-material dimensions of well-being such as the social, political, and environmental conditions of a country, income measures give an incomplete, and perhaps misleading, picture of development. Not all have agreed with this characterization of the primacy of income growth in development policy, with Srinivasan (1994) stating outright that "In fact, income was never even the primary, let alone the sole, measure of development, not only in the minds of economists but, more importantly, among policymakers". Irrespective of this debate, the HDI has become a widely reported and followed development indicator (Morse 2023).

The theoretical justification for the HDI is Sen's capability approach to human development, which has been laid out in several articles and books (see, e.g., Sen (1985,1999); Nussbaum and Sen (1993)). The capability approach focuses on the quality of life that individuals are able to achieve and is based on the concepts of "functionings" – states of being or doing, and "capabilities" – the "functionings" that a person has effective access to and can choose among. The intention of the HDI is to capture, more precisely than income per capita can, this idea of "judging individual advantage in terms of the respective capabilities, which the person has, to live the way he or she has reason to value" (Sen (1999)).

A great deal of simplification has been employed in moving from a philosophical theory emphasizing choice and capabilities to a quantifiable HDI metric. The simplifications have proved controversial. The first relates to what is included in the index. While acknowledging that choices could be "infinite and change over time," "range from political, economic and social freedom to opportunities for being creative and productive, and enjoying personal self-respect and guaranteed human rights", the HDI limited its focus to three domains: "three essential ones are for people to lead a long and healthy life, to acquire knowledge and to have access to resources needed for a decent standard of living" (UNDP 1990).

To construct the HDI, a long and healthy life has been captured by a measure of life expectancy; education or the ability to acquire knowledge by some measure of schooling; and access to resources needed for a decent standard of living by a measure of income per capita, where the precise measures of each core value have changed over time. To aggregate subcomponents measured in different units (years of education; years of life, and monetary units), each core value is normalized to a 0-1 scale, becoming a "dimension index" before being combined to form the HDI. The normalization entails assumptions about min and max values for each core variable.

The exclusion of variables for social and political freedoms has been justified by the need for data transparency, availability and manageability (ul Haq (1995)). A substantial literature exists of proposed alternatives that include elements left out by UNDP; e.g., Prados de la Escosura (2021) includes a fourth dimension of "liberal democracy" in its (renamed) Augmented HDI and Bilbao-Ubillos (2013) proposes the Composite Dynamic HDI, which includes indicators for poverty, gender situation, sustainability, and personal safety. Amendola et al (2023) provides a literature review and critical examination of several other suggested alternatives. However, the UNDP has never changed from only including the core values of education, health, and standard of living in the HDI. While research contributions proposing alternative HDI's may discuss the role of income with respect to capabilities (e.g., Sagar and Najam (1998)), in implementing their alternatives they have all used income in their composition, using whatever income criteria HDR was using at the time.

Among the core values, the inclusion of income has been the most controversial. With this, the HDI combines stock variables (education and health) with a flow variable (income); includes both outcomes (education, health) and means (income), and includes the very item – income – it was created to replace. In theory and practice, the role of income has been paradoxical. On one hand, its inclusion has been justified to reflect that economic growth increases the resources and options available for social progress (ul Haq (1995)), with the 1990 HDR stating that "…income is a proxy measure for the choices people have in putting their capabilities to use" and Anand and Sen (2000) directly noting that income represents "the command over resources" and its use in the HDI "is strictly as a residual catch-all, to reflect something of other basic capabilities not already incorporated in the measures of longevity and education." This suggests that in normalizing income to a dimension index, no cap should be placed on its maximum value, thus allowing income to fully embody the concepts of individual choice, creative opportunities, etc., and also allowing for change over time, as Zambrano (2017) notes that "Which functionings are essential to monitor can also evolve over time, and vary both across and within countries".

On the other hand, however, ul Haq (1995) suggests that "The HDI is based on a cut-off point defined by a level of income regarded as adequate for a reasonable standard of living and for a reasonable fulfilment of human capabilities", and HDR 2005 states that "…achieving a respectable level of human development does not require unlimited income" (UNDP 2005). Klugman et al (2011) provides detail on the historical progression of income normalization in the HDI. The current maximum value used for the income dimension is $75,000, for reasons discussed in Section 2. As the HDI is a metric intended for all countries – even those with higher educational, health, and income levels – it is problematic to acknowledge income's role in capability enhancement and at the same time limit its role. While the income bounds are important as they should match the underlying theory, they also have empirical and policy implications as country rankings are affected by the imposed income bounds (Panigrahi and Sivramkrishna (2002)).

The second issue with respect to income relates to the treatment of diminishing marginal effects of income on capabilities, which is impacted by the aggregation function used to combine the core values into the HDI. The UNDP moved from an arithmetic mean to a geometric mean in 2010, to "capture how well rounded a country's performance is across the three dimensions" (UNDP 2010). With the geometric mean, as any one dimension index approaches its minimum value, the HDI approaches zero, even if the other dimensions are at their maximum values. By penalizing inequality, the geometric mean embodies complementarity, while with the pre-2010 arithmetic mean the three dimensions are treated as substitutes. With the currently used geometric mean, "high" income not used for development as captured by education and health results in a lower HDI than with the arithmetic mean HDI (where income enters additively); a view suggested to be more consistent with Sen's theory (UNDP 2010).

In a series of influential papers, Ravallion (2011, 2012a, 2012b) provides critiques of the move to the geometric mean, including that it imposes "extra" diminishing returns to income, results in a steep income gradient in its implicit valuations of life expectancy (implicitly putting a much lower value on an extra year of life in poorer countries than rich ones), and proposes a generalized arithmetic mean as an improvement. Zambrano (2014, 2017) provides critiques of Ravallion (2012a) and suggests a generalized geometric mean as an improvement. Klugman et al (2011) provides further context on this controversy and more historical detail on this important debate.

This paper focuses on the treatment of income. We discuss recent research which does not support the current max income used. We use underlying data from 2016 (a "representative" year) to examine distributional changes as well as specific country rankings produced by the current geometric mean HDI formulation and the two major competitors put forth in the literature, a generalized arithmetic mean (i.e. a generalized pre-2010) aggregation function suggested by Ravallion (2012a) and a generalized geometric mean (i.e. a generalized post-2010) function suggested by Zambrano (2017). We examine these three indices at currently used income bounds and proposed bounds that are conceptually and empirically sound and which we suggest more fully embody the capability approach as initially laid out. We find that the HDR should update the income bounds used to derive the income dimension and include all three aggregation formulations, along with prominent descriptions of the assumptions underpinning each, for policymakers and the public to consider.

2. Income and the HDI

The two main issues with respect to income are related to satiation and concavity. Is there a satiation point, whereby income beyond a specific level no longer contributes to individuals' capabilities? And, independently of satiety, does each unit of income contribute equally to well-being, or does income transform into capabilities at a declining rate – and if it does, when do diminishing returns set in, and how concave should the relationship be? These issues are addressed by how income is re-scaled and by the functional form used to combine the three core values.

First consider the normalization of each core value to a standardized 0 – 1 dimension index, which requires assumptions on the minimum and maximum values for each core value. These "goalposts" act as "natural zeros" and "aspirational targets" for each core value (HDR various years (e.g. UNDP 2021/2022)), where any achievement beyond the "aspirational target" does not contribute to the HDI.

For health and education, the dimension indices are:

$$\boldsymbol{Dimension\ Index} = \frac{actual\ value - minimum\ value}{maximum\ value - minimum\ value} \tag{1}$$

The income dimension is calculated as:

$$\boldsymbol{Income\ Dimension\ Index} = \frac{\ln\,(actual\ value) - \ln\,(minimum\ value)}{\ln\,(maximum\ value) - \ln\,(minimum\ value)} \tag{2}$$

where the minimum income is \$100, the maximum income is \$75,000, and income is represented by real GNI/capita.

2.1. Upper and Lower Bounds

There is disagreement in the literature on exactly what the maximum value "goalpost" or "aspirational target" represents. According to Klugman et. al. (2011), it "was conceived as a 'satiation point' beyond which additional increments did not contribute to the expansion of capabilities". However, according to Zambrano (2014, 2017), the maximum represents the "highest level any society has been known to achieve. The upper bound can be as high as normatively desired". In some years, observed maximum income values have been used while in others fixed values have been used, although the fixed value itself has changed seemingly arbitrarily, with little to no explanation. In 1990, e.g., the upper bound was set to the official poverty line in nine industrial countries (\$8,193 in 2008 dollars). In 1999, as well as 2009, an upper bound of \$40,000 was set. In 2013, the maximum income was set to the observed maximum of \$87,478 (Qatar, 2012), while beginning in 2014 and to the present, the maximum bound has been set to \$75,000.

The HDR (HDR multiple years, e.g., UNDP (2021/2022)) has justified the currently used maximum value of \$75,000 by stating that "Kahneman and Deaton (2010) have shown that there is virtually no gain in human development and well-being from annual income beyond \$75,000." However, Kahneman and Deaton (2010)'s results are not quite this broad; in fact, they define and discuss two measures: "emotional well-being" (also known as "experienced well-being"), the emotional quality of an individual's everyday experience (frequency and intensity of joy, stress, sadness, etc.), and "life evaluation" (also known as "evaluative well-being"), the thoughts that people have about their life when they pause and reflect. Analyzing U.S. survey data (the Gallup-Healthways Well-Being Index, a daily survey of 1,000 U.S. residents in 2008 to 2009), Kahneman and Deaton (2010) find that higher income continues to improve individuals' life evaluation, but emotional well-being plateaus at $75,000. HDR's decision to use the emotional well-being results rather than the life evaluation results is interesting, as Kahneman and Deaton (2010) explicitly do not suggest either as a preferred measure for policy. On the contrary, Deaton (2008) indicates that despite shortcomings, life evaluation, not emotional well-being, "may provide a useful summary of the different components of peoples' capabilities".

More recent empirical research calls into question the $75,000 upper bound, whether emotional well-being or life satisfaction is the concept being used. Killingsworth (2020) uses over 1.7 million experience sampling reports collected via smartphones for real-time reports on emotional well-being, life satisfaction, and income in the U.S. and finds robust relationships between higher income and higher emotional well-being and life satisfaction, with no evidence that either measure plateaus at $75,000. To reconcile these contradictory findings with Kahneman and Deaton (2010), Killingsworth and Kahneman engaged in an adversarial collaboration. In Killingsworth et al (2023), they reconsider the nature of the Gallup survey questions used by Kahneman and Deaton (2010) and the lack of analysis on different sub-sample data done by Killingsworth (2021). Killingsworth et al (2023) finds that for an unhappy minority of 15-20% of people, unhappiness diminishes with increased income up to a level of $100,000, but little beyond that threshold. For the other 80% - the happy majority - emotional well-being continues to increase with increases in income, with the happiest 30% of people exhibiting an accelerated increase beyond $100,000.

Stevenson and Wolfers (2008, 2013) and Sacks et al (2012) use data on a large sample of countries, both rich and poor, and several survey sources for happiness and life satisfaction data over several years. They find that within a country, increases in GDP per capita are positively correlated with life satisfaction and also find no evidence of a satiation point. Combined with Killingsworth (2021) and Killingsworth et al (2023) results, HDR's reasoning for the $75,000 upper income bound has been refuted and should be replaced by the maximum realized income, which HDR has sometimes used, e.g., in 2013. By not limiting income's contribution to development, this also supports an interpretation of the capabilities approach that fully allows for individual choice over what is valued.

Regarding the minimum value used for income as a "natural zero", as with the maximum, different values have been used in different years. In some years, observed values have been used while in others these values have been fixed - although the fixed value itself has changed. For example, in 2009, $100 was used for the minimum; in 2010 the lower bound was set to an observed value of $163, (Zimbabwe, 2008 PPP dollars), while beginning in 2011 and to the present, the minimum has been set to $100.

The theoretical justification to support the chosen minimum has been vague at best. According to the HDR (UNDP multiple years, e.g., UNDP 2021/2022), "The low minimum value for gross national income (GNI) per capita, $100, is justified by the considerable amount of unmeasured subsistence and nonmarket production in economies close to the minimum, which is not captured in the official data." According to Klugman et al (2011): "It seems that these lower bounds can best be perceived as subsistence values— values below which we would not expect a society to survive." Klugman et al (2011) cite various researchers who have estimated minimum subsistence income amounts that are much higher than what has actually been observed: Madison's (2010) estimate is $604 in 2008 international dollars; Bairoch's (1993) is $446 in 2008 international dollars; and Becker et. al. (2005) determine that the level of income at which an individual would be indifferent between being dead and alive is $353 in 1990 prices ($518 in 2008 prices). All of these estimates are actually much higher than those at which people have actually lived: $163 in Zimbabwe in 2008 international dollars.

Thus the $100 value currently used as a minimum value has little theoretical or empirical support. No research is cited by UNDP to justify the specific value of $100 for nonmarket production in lower income economies – as opposed to, say, using $90 or $50. Considering that unmeasured, non-market production has a greater prevalence for lower income countries, it makes sense not to rely on the minimum observed income for a country as the lower bound. Given the difficulty in estimating the minimum income needed for survival as noted earlier and the penalty imposed on low income countries close to the boundary, the lower bound should be decreased from its current level of $100. What the value should be, however, is arbitrary.

2.2. Diminishing Returns

Unlike with education and health, HDR assumes that income transforms into capabilities at a declining rate. How this concavity in income has been attained – and the degree of concavity – has varied. From 1991 – 1998 an Atkinson formula was used such that the impact of income declined steeply at discontinuous rates at multiples of the poverty level (from 1994 – 1998 global average GDP per capita was used instead of the poverty level), with no upper cap on income. Only income below the poverty line (1991 – 1993) or global average GDP per capita (1994 – 1998) was fully weighted. From 1999 to 2009 the base 10 log of income was used, with a change in 2010 to the natural log for consistency with the economic literature. The degree of diminishing returns also depends on the aggregation function used to combine the three dimensional indices. The aggregation function also has implications for the marginal rates of substitutions among not only the dimensional indices but also the underlying core values.

2.3. Aggregation Functions

Prior to 2010, an arithmetic mean HDI_{ari} was used to form the composite index.

$$\boldsymbol{HDI_{ari}} = (I_{health} + I_{education} + I_{income})/3 \tag{3}$$

From 2010 to the present, a geometric mean has been implemented for the HDI. Call this the geometric mean HDI, or. HDI_{geo}

$$\boldsymbol{HDI_{geo}} = (I_{health} * I_{education} * I_{income})^{\frac{1}{3}} \tag{4}$$

The arithmetic mean implies a constant marginal rate of substitution among the three dimension indices, that is, perfect substitutability. An increase in the education index, e.g., exactly offsets an equal decrease in the health index, regardless of the levels of the dimensions, and a high income dimension index improves the HDI even if the health and education dimension indices are at their minimum values. To "capture how well rounded a country's performance is across the three dimensions" (UNDP 2010), the geometric mean HDI was introduced in 2010 to embody imperfect substitution, or complementarity. With the geometric mean, "high" income not used for human development - as captured by education and health - is penalized with a lower HDI score compared to an arithmetic mean.

Ravallion (2012a) heavily criticized the move to the geometric mean by showing its further implications beyond complementarity - what he termed its "troubling tradeoffs" - as income approaches the minimum value used in its normalization, the contributions of longevity and education approach zero. This automatically penalizes countries with very low incomes but relatively higher achievements in education and health. Using 2010 data, Ravallion (2012a) shows sub-Saharan African countries are particularly affected by this feature. Regarding diminishing returns, Ravallion (2011, 2012) points out that a geometric mean makes the HDI concave in income, so there is no need to also take the natural log of income in the dimension index; using both means that HDI_{geo} is "extra" concave in income.

2.4. Ravallion (2012a) and Zambrano (2017)'s Proposed Alternative HDI Formulations

Given the geometric mean HDI's steep income gradient in its implicit valuations of life expectancy and schooling, Ravallion (2012a) suggests a generalized form of the pre-2010 arithmetic mean HDI proposed by Chakravarty (2003) that avoids these "troubling tradeoffs" yet allows for imperfect substitution:

$$\boldsymbol{HDI_R^C} = \quad ((I_{health})^r + I(_{education})^r + (I_{income})^r)/3 \tag{5}$$

For $0 < r < 1$, where "r" is a free parameter and in the limit for $r = 1$ simplifies to the Old HDI. The dimension indices, including for income, are calculated as in equation (1). Ravallion (2012a) does not impose additional concavity beyond that given by the fractional exponent. Using the HDI_R^C with 2010 data, Ravallion (2012a) shows it gives a much less steep income gradient in the valuations of longevity and schooling than does the currently used geometric mean HDI. In the analysis that follows, $r = 0.5$ is used, as in Ravallion (2012a).

Zambrano (2017) takes a different approach to the "troubling tradeoffs" problem. Zambrano (2017) finds that the natural log transformation of income in the new HDI is approximately five times more important than its multiplicative structure in explaining the extremely large variations in tradeoffs between longevity and income noted by Ravallion (2012a). Zambrano (2017) also concludes that although the rankings produced by Ravallion (2012a) are similar to rankings by HDI_{geo} using data from 2010, when they differ, HDI_{geo} produces "more intuitive" rankings. As such, Zambrano (2017) proposes a generalized functional form that has the multiplicative structure of the currently used geometric mean as a subcase.

In Zambrano (2017)'s proposed index, if education or health achievements increase by a fixed proportion, there is an increase in the education or health index by the same proportion. However, if income grows by a fixed proportion, the growth rate of the income index grows by a fraction r of that proportion, where r is the same for all income levels, giving less concavity to income than in HDI_{geo}. Zambrano (2017) labels this "proportional capabilities growth" (versus the current geometric mean HDI, whereby the amount of an income change needed for a given increase in the income index is proportional to the initial level of income, which Zambrano (2017) labels "partial capabilities growth"). Zambrano (2017) suggests that proportional capabilities growth provides more "sensible" tradeoffs between income and longevity and health.

For the Zambrano index:

$$\boldsymbol{HDI_{zam}} = \quad (I_{health} \, * \, I_{education} \, * \, I_{income})^{\frac{1}{3}} \tag{6}$$

where the dimension indices for health and education are given by equation 1. The income the dimension index is given by:

$$\boldsymbol{Income\ Dimension\ Index} = \frac{(actual\ value)^r - (minimum)^r}{(maximum)^r - (minimum)^r} \tag{7}$$

for $0 < r \leq 1$ and for $r = 0$, $Income\ Dimension\ Index = \frac{\log(actual) - \log(minimum)}{\log(\text{maximum}) - \log(minimum)}$. As r goes to 0, the proposed Zambrano index simplifies to HDI_{geo}.

Zambrano (2017) suggests the free parameter r can be informed by "decision makers" and "public opinion" and that tradeoffs can be elicited by asking the public questions such as:

> *"Consider country 'A' with Life Expectancy (h) and Income Level (y) equal to the median of those variables worldwide (about 73 years and 7500 PPP dollars per capita, respectively). What percent of such annual per capita income do you believe people in such country should be inclined to sacrifice to gain a year in life expectancy and keep their level of human development constant?"*

The percentage of income determined from such a question, M, can be used to calculate the value of r

according to:

$$\boldsymbol{M} = \frac{1-(\frac{7500}{minimum\ income})^{-r}}{73-minimum\ health} * \frac{1}{r} \quad (8)$$

Using 2010 data and $r = 0.5$, Zambrano (2017) finds that his proposed HDI produces more "sensible" tradeoffs among the core dimensions of income and longevity and health compared to the tradeoffs obtained using either HDI_{geo} or HDI_R^C. In the analysis that follows, $r = 0.5$ is used, as in Zambrano (2017).

3. *Methodology, Analysis and Discussion*

3.1. Methodology

Examining proposed alternatives to the HDI by considering correlation coefficients, charts of distributional changes in rankings, specific country movers up or down the league table, and visual comparisons is the method used for assessment in this literature: e.g., Sagar and Najam (1998), Prados de la Escosura (2021), Bilbao-Ubillos (2013), Amendola (2023), Ravallion (2012a) and Zambrano (2017), and we use these methods.

We begin by considering the impact of changing the income bounds for the currently used geometric mean (HDI_{geo}) on country rankings. Given the analysis in section 2, for our new income bounds we use a minimum of $50 rather than $100 to provide more "breathing room" for low income countries. For the maximum value, we use the observed value of $129,916 (Qatar's income per capita in 2016) rather than $75,000.

Next, we compare country rankings using the HDI_{geo} and alternatives proposed by Ravallion (2012a) (HDI_R^C) and Zambrano (2017) (HDI_{zam}), first using the current income bounds and then using the new bounds. We also compare, separately, HDI_R^C using the old and new bounds, and HDI_{zam} using the old and new bounds. Finally, we compare all three indices using the proposed income bounds and also look more specifically at pairwise comparisons. We use data from 2016, a representative year (far enough removed from the financial crisis of 2008, prior to Covid, and close to the Ravallion (2012a) and Zambrano (2017) proposals), for 188 countries, to consider distributional changes and specific country rankings. Data is available from https://hdr.undp.org/data-center/documentation-and-downloads. As in Ravallion (2012a) and Zambrano (2017), a value of 0.5 is used for the free parameter in each.

3.2. Analysis

3.2.1. Current Geometric Mean and Revised Income Bounds

Figure 1. and Table 1. present information on the distributional changes when comparing country rankings generated by the currently used geometric mean with the current income bounds of $100 and $75,000 and HDI_{geo} with the proposed income bounds of $50 and $129,916. The two series are very highly correlated, with a correlation coefficient of 0.99960. The greatest downward movement is 4 spots (both Oman and Kuwait) and the greatest increase is 6 spots (Qatar).

Table 1. Summary of Change in Rank from Figure1.

Change in Rank	% of Countries
None	40
+/- 1 spot	75
+/- 2 spots	87
+/- 3 spots	97

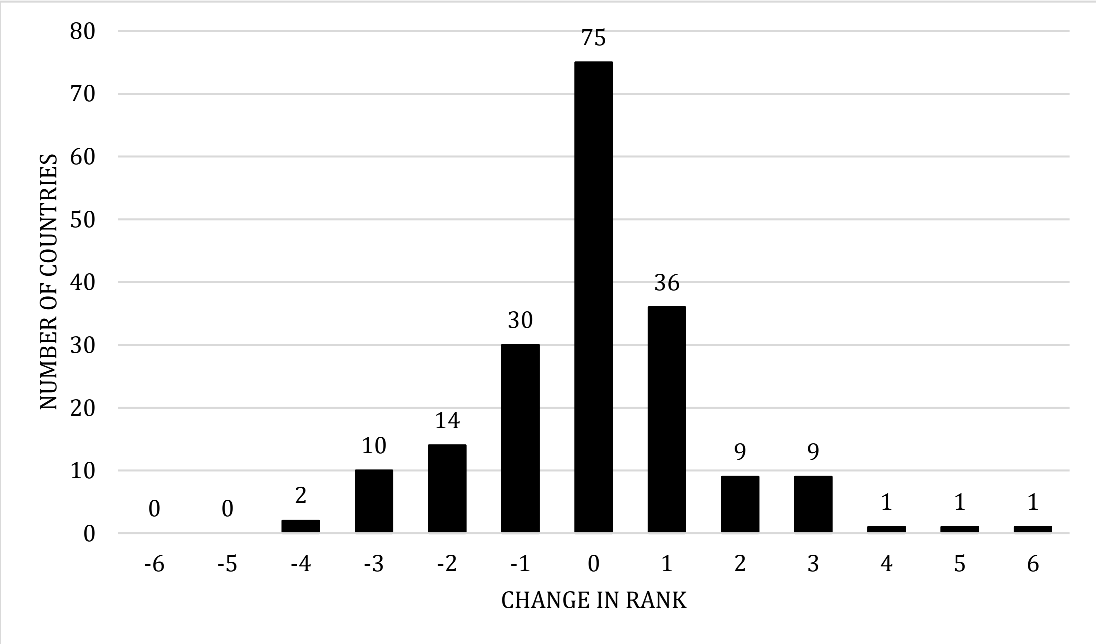

Figure 1. HDI_{geo} (min \$50, max \$129,916) vs. HDI_{geo} (min \$100, max \$75,000).

The top ten ranked countries (Table 2) and bottom ten (Table 3) remain the same with the new min and max income bounds, with minor changes in specific country rank. The U.S. maintains its rank of 11 in both, while Zimbabwe, a country used by Ravallion (2012a) to illustrate the negative impact of moving from the pre-2010 arithmetic mean to the geometric mean for countries with low income but relatively higher education and health values, jumps 2 spots from 155 to 153 with the HDI_{geo} and new income bounds.

Four countries have an income above the currently used maximum of \$75,000. The impact of changing the income bounds for these countries is shown in Table 4. Interestingly, the wider range of income offsets any benefit of more "balanced" core values for Singapore, Lichtenstein, and Kuwait, which now have income below the upper bound, as they all fall in the rankings. Allowing its full income to contribute to its score, Qatar increases six spots from 35 to 29.

Table 2. Top 10 countries ranked by HDI_{geo}.

Min=\$100; Max=\$75,000

Country	Income Index	New HDI	Rank
Norway	0.984340381	0.94942	1
Switzerland	0.956849691	0.93913	2
Australia	0.915343604	0.93868	3
Germany	0.922835677	0.92567	4
Singapore	1	0.92487	5
Denmark	0.921213295	0.92465	6
Netherlands	0.927222271	0.92431	7
Ireland	0.918747018	0.92275	8
Iceland	0.893534531	0.92111	9
Canada	0.91449362	0.92028	10

Min=\$50; Max=\$129,916

Country	Income Index	New HDI	Rank
Norway	0.916940184	0.92724	1
Australia	0.858847119	0.91896	2
Switzerland	0.893793908	0.91803	3
Germany	0.865155204	0.90597	4
Denmark	0.86378921	0.90502	5
Singapore	0.935377734	0.90450	6
Netherlands	0.868848574	0.90449	7
Ireland	0.861712685	0.90324	8
Iceland	0.840484582	0.90251	9
Canada	0.85813146	0.90098	10

Table 3. Bottom 10 countries ranked by HDI_{geo}

Min=$100; Max=$75,000

Country	Income Index	New HDI	Rank
Sierra Leone	0.411976437	0.420312	179
Eritrea	0.408040961	0.420153	180
South Sudan	0.443376537	0.418303	181
Mozambique	0.362000866	0.41759	182
Guinea	0.356366637	0.414186	183
Burundi	0.292026049	0.403765	184
Burkina Faso	0.412796397	0.40174	185
Chad	0.451831488	0.396073	186
Niger	0.330123155	0.352641	187
Central African Republic	0.267468604	0.35244	188

Min=$50; Max=$129,916

Country	Income Index	New HDI	Rank
Mozambique	0.392950349	0.429167	179
Eritrea	0.431714627	0.428127	180
Sierra Leone	0.435028171	0.42801	181
Guinea	0.38820651	0.426171	182
South Sudan	0.461466044	0.423917	183
Burundi	0.334033805	0.422265	184
Burkina Faso	0.43571855	0.409043	185
Chad	0.468584841	0.400909	186
Central African Republic	0.313357228	0.371542	187
Niger	0.366110343	0.365015	188

Table 4. Countries with income above $75,000 using HDI_{geo}

Country	*Min=$100; Max=$75,000*			*Min=$50; Max=$129,916*			Δ Rank
	Income Index	New HDI Value	Rank	Income Index	New HDI Value	Rank	
Singapore	1	0.92	5	0.935378	0.90	6	-1
Liechtenstein	1	0.91	15	0.930235	0.89	16	-1
Qatar	1	0.86	35	1	0.86	29	6
Kuwait	1	0.80	51	0.931935	0.78	55	-4

We see that that the revised income bounds have an overall minor impact on country rankings, suggesting that implementing these bounds would not be disruptive to current users of the HDI. Given this and the better theoretical justifications for the revised bounds, going forward the HDI_{geo} should be calculated using the revised income bounds.

3.2.2. Alternatives at Current Income Bounds and Revised Income Bounds

Next, consider the two proposed alternatives to HDI_{geo}: HDI_R^C and HDI_{zam}, each implemented using the current income bounds (Figure 2) and the revised income bounds (Figure 3). For both sets of income bounds, HDI_{zam} has lower values than HDI_R^C, with a bigger gap between the two indices at the lower HDI values. For both sets of income bounds, HDI_{zam} values are generally less than those for HDI_{geo}, with the biggest differences occurring at the lower HDI values. For both sets of income bounds, HDI_R^C is above HDI_{geo} at the lower and higher index levels, and below in the intermediate range. We see all three HDI versions converging as the index approaches the upper bound of the HDI.

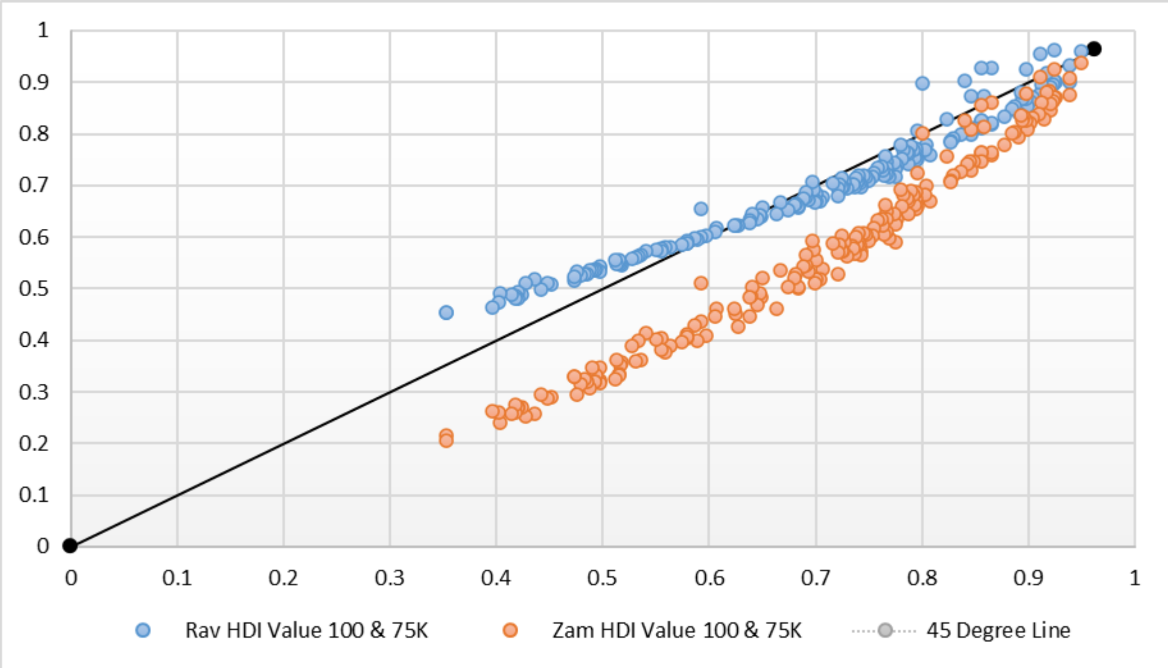

Figure 2. HDI_{geo} (45°), HDI_{zam}, & HDI_R^C with Min=\$100 and Max=\$75,000.

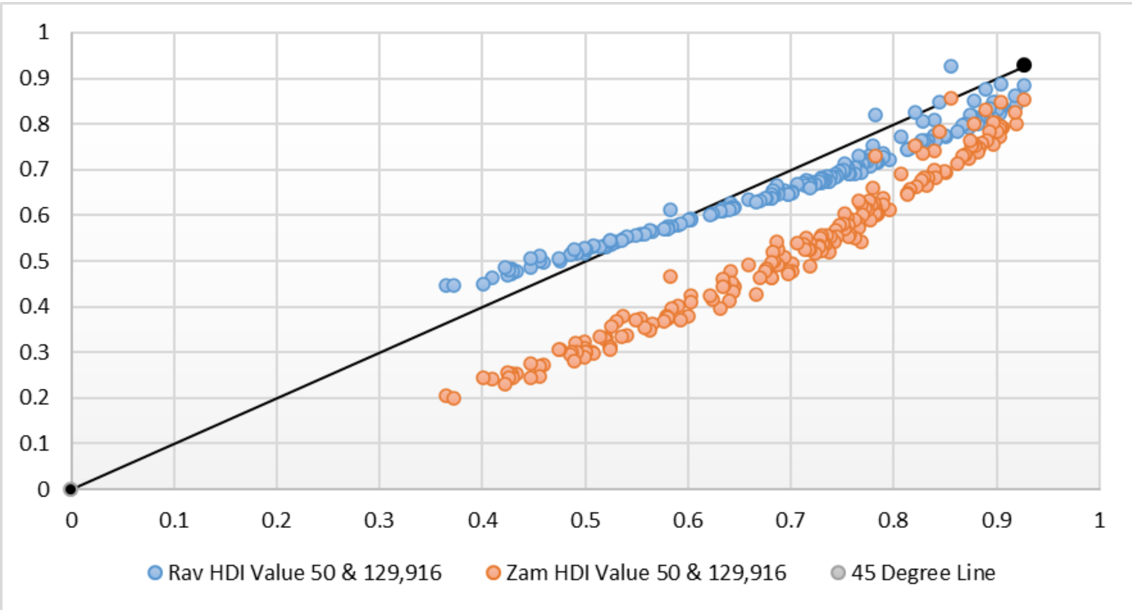

Figure 3. HDI_{geo} (45°), HDI_{zam}, & HDI_R^C with Min=\$50 and Max=\$129,916.

Next, consider more specifically how country rankings are impacted by moving to the new income bounds for each of the two proposed alternatives to HDI_{geo}. Figure 4 and Table 5 show the results when comparing HDI_R^C with bounds (\$100, \$75,000) to results for HDI_R^C with bounds (\$50, \$129,916). The two series are very highly correlated, with a correlation coefficient of 0.99906. The greatest downward movement is 13 spots (Gabon), while the greatest increase in rank is a movement of 7 positions (Ukraine). As was found with HDI_{geo}, the changes in rank appear minor enough to support moving to the new income bounds, which have greater theoretical support than the currently used min and max income levels.

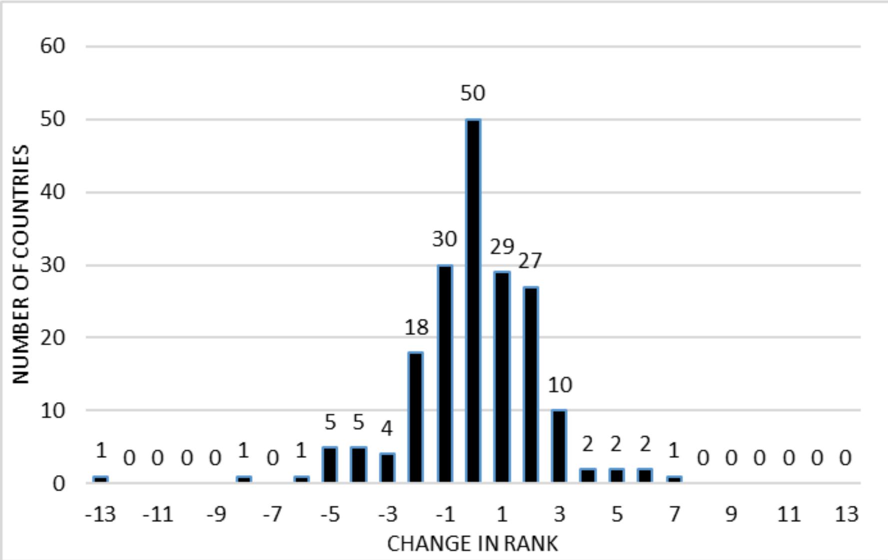

Figure 4. Change in Rank from HDI_R^C (Min=$100; Max=$75,000) to HDI_R^C (Min=$50; Max=$129,916).

Table 5. Summary of Change in Rank from Figure 4.

Change in Rank	% of Countries
None	27%
+/- 1 spot	58%
+/- 2 spots	82%
+/- 3 spots	89%

Comparing Figure 1 and Table 1 to Figure 4 and Table 5, we see that HDI_R^C exhibits more dispersion with the proposed wider income bounds than does HDI_{geo}.

Table 6 focuses on the impact on the four countries with income above $75,000 using HDI_R^C with the new min and max income values. At the currently used min income of $100 and max income of $75,000, each of the four countries has a more prominent position at the top of the league table compared to when HDI_{geo} is used. HDI_R^C embodies substitutability so marginal increases in income more fully contribute to higher HDI scores.

As with HDI_{geo}, Singapore and Lichtenstein fall one spot, while Kuwait falls five spots (versus four) when using the proposed income bounds. HDI_R^C allows increased income to be fully reflected in the index and consequently Qatar increases five spots from 6 to 1, versus from 35 to 29 with HDI_{geo} (Table 4).

Table 6. Countries with income above $75,000 using HDI_R^C.

Country	*Min=$100; Max=$75,000*			*Min=$50; Max=$129,916*			Δ Rank
	Income Index	**Rav**	**Rank**	**Income Index**	**Rav**	**Rank**	
Singapore	1	0.96	1	0.60	0.89	2	-1
Liechtenstein	1	0.96	3	0.58	0.88	4	-1
Qatar	1	0.93	6	1.00	0.93	1	5
Kuwait	1	0.90	14	0.59	0.82	19	-5

Finally, consider rankings by HDI_{zam} using the current income bounds of $100 and $75,000 versus rankings by HDI_{zam} using bounds of $50 and $129,916. Figure 5 and Table 7 show the results.

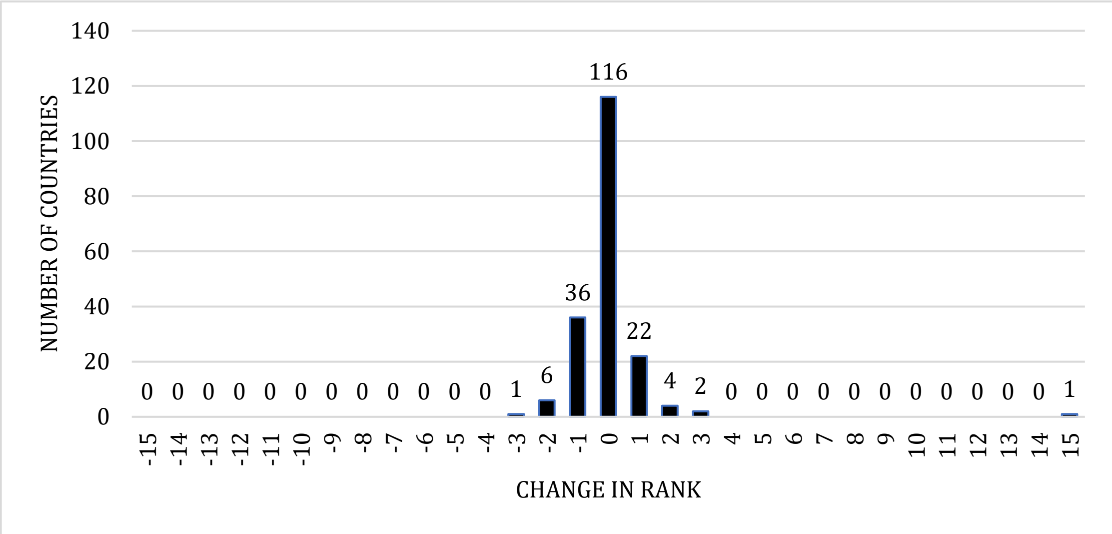

Figure 5. Change in Rank from HDI_{zam} (Min=$100; Max=$75,000) to HDI_{zam} (Min=$50; Max=$129,916).

Table 7. Summary of Change in Rank from Figure 5.

Change in Rank	% of Countries
None	62%
+/- 1 spot	92%
+/- 2 spots	98%
+/- 3 spots	99%

The two series are very highly correlated, with a correlation coefficient of 0.99968. The HDI_{zam} is the least sensitive of all three alternative HDI's to changes in the min and max values in terms of overall distributional changes. While the change in rank for Qatar is the greatest among the three HDI formulations as it jumps from 16 to 1, every other country's rank changes within the (-3, +3) range.

Table 8 shows the impact on the four countries with income above $75,000. As with HDI_{geo} and HDI_R^C, Singapore and Lichtenstein fall one spot, while Kuwait does not change in rank. Qatar's increase of fifteen spots shows that at very high incomes, HDI_{zam}'s proportional capabilities growth, along with the new bounds, "overcomes" the unbalanced income penalty of its geometric mean.

Table 8. Countries Affected by Increase in Maximum Income using HDI_{zam}.

Country	*Min=$100; Max=$75,000*			*Min=$50; Max=$129,916*			Δ Rank
	Income Index	**Zam**	**Rank**	**Income Index**	**Zam**	**Rank**	
Singapore	1	0.92	2	0.77	0.85	3	-1
Liechtenstein	1	0.91	3	0.76	0.83	4	-1
Qatar	1	0.86	16	1.00	0.86	1	15
Kuwait	1	0.80	31	0.76	0.73	31	0

The changes in country rankings when applying new bounds on income of $50 and $129,916 to construct the income dimension index for the HDI_R^C, and HDI_{zam} alternatives support the conclusions reached with HDI_{geo}: the changes in rank do not appear significant enough to justify continuing to use the current poorly supported min and max values of $100 and $75,000.

3.2.3. Comparisons of Alternative HDI's with New Income Bounds

How do country rankings vary when compared across the alternative HDI formulations, with each HDI using the proposed bounds of $50 and $129,916 to construct the income dimension index? First consider the HDI_R^C ranking compared to HDI_{geo} ranking (Figure 6 and Table 9).

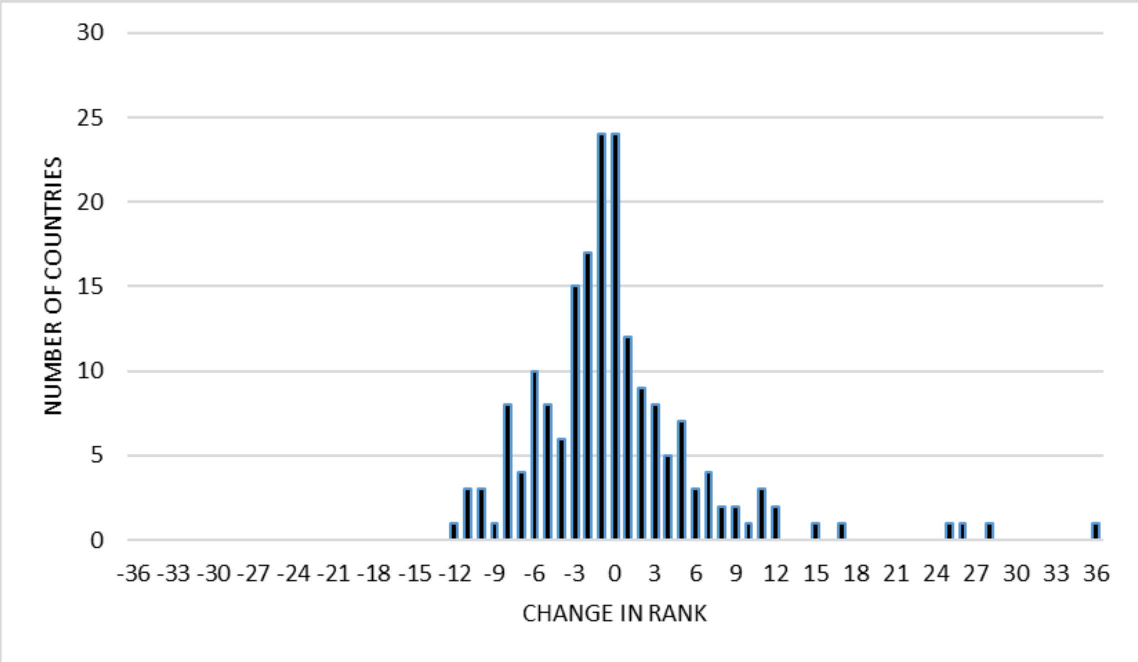

Figure 6. Changes in Rank from HDI_{geo} to HDI_R^C (Min=$50; Max=$129,916).

Table 9. Summary of Change in Rank from Figure 6.

Change in Rank	% of Countries
None	13%
+/- 1 spot	32%
+/- 2 spots	46%
+/- 3 spots	58%
+/- 12 spots	97%

The two series are highly correlated, with a correlation coefficient of 0.99269. The greatest downward movement is 12 spots (New Zealand) and the greatest increase is 36 spots (Kuwait). Qatar changes 28 spots in rank (29 in the HDI_{geo} ranking and first with HDI_R^C).

Next consider the HDI_{zam} ranking compared to the ranking by HDI_{geo} with both using income bounds of $50 and $129,916 (Figure 7 and Table 10).

The greatest downward movement is 21 spots (Cuba) and the greatest increase is 28 spots (Qatar, from 29 to 1). The two series are highly correlated, with a correlation coefficient of 0. 98969.

Next consider the HDI_R^C ranking compared to that by HDI_{zam} with both using income bounds of $50 and $129,916 (Figure 8 and Table 11).

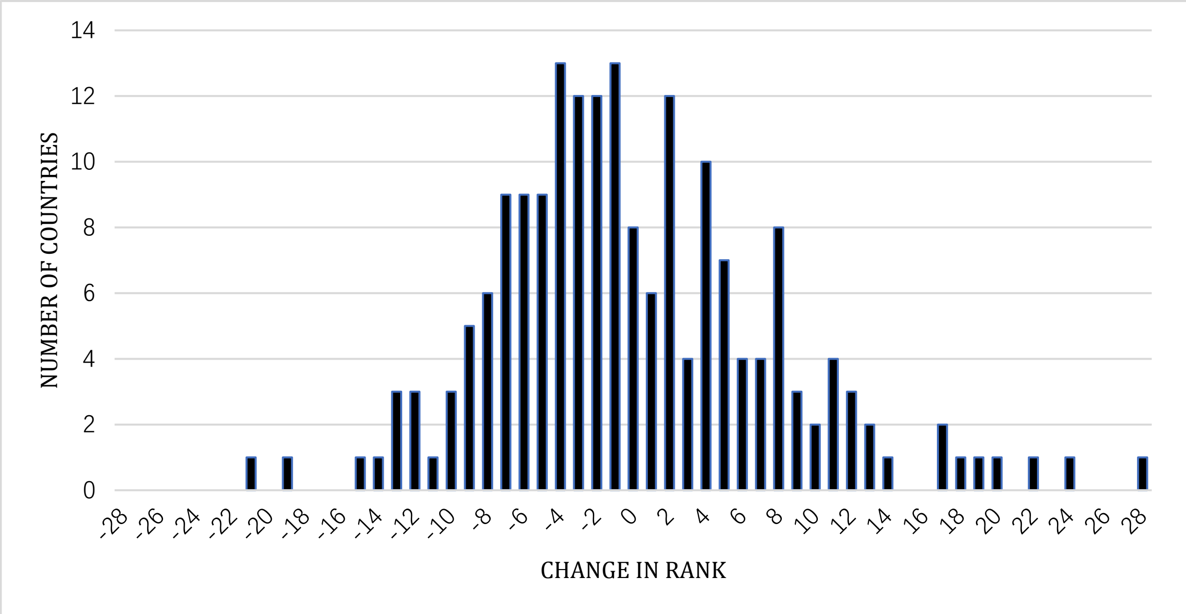

Figure 7. Change in Rank from HDI_{geo} to HDI_{zam} (Min=$50; Max=$129,916).

Table 10. Summary of Change in Rank from Figure 7.

Change in Rank	% of Countries
None	4%
+/- 1 spot	14%
+/- 2 spots	27%
+/- 3 spots	36%
+/- 15 spots	95%

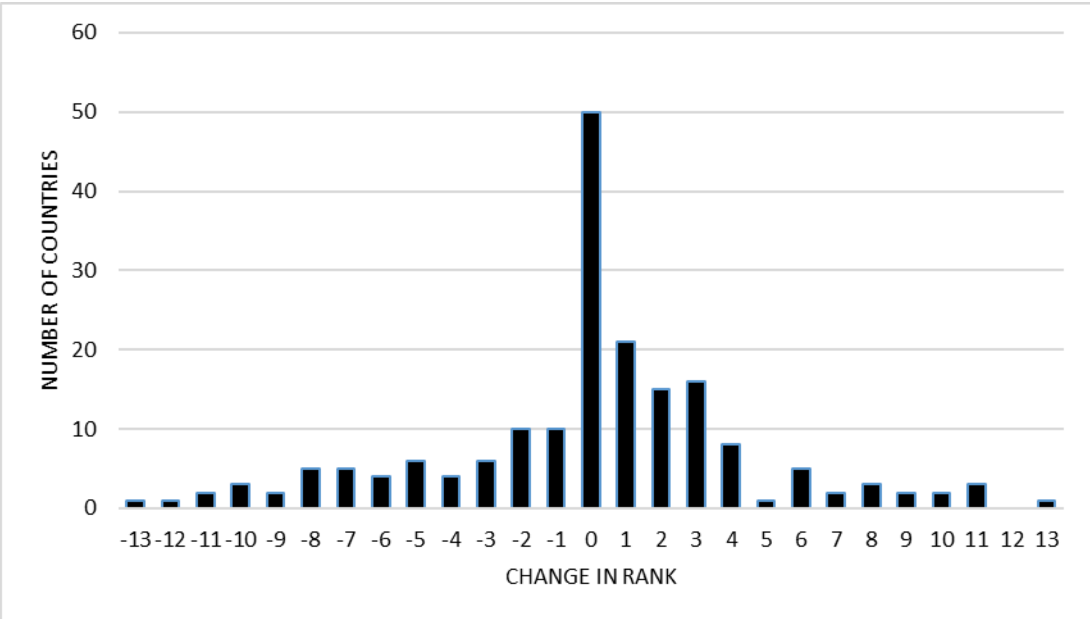

Figure 8. Change in Rank from HDI_R^C to HDI_{zam} (Min=$50; Max=$129,916).

Table 11. Summary of Change in Rank from Figure 8.

Change in Rank	% of Countries
None	27%
+/- 1 spot	43%
+/- 2 spots	57%
+/- 3 spots	68%
+/- 12 spots	98.9%
+/- 13 spots	100%

The greatest downward movement is 13 spots (Comoros) and the greatest increase is 13 spots (Gabon). The two series are highly correlated, with a correlation coefficient of 0.99658.

Based on distributional changes, HDI_R^C is closer to HDI_{geo} than is HDI_{zam}. When comparing HDI_R^C to HDI_{zam}, we see the greatest similarity in rankings among the three alternatives: these series have the highest correlation (but again noting that for each comparison, all series are very highly correlated).

To elicit information about the complex interaction of assumed income bounds, the aggregation function, and actual underlying data, we next focus on a more granular level by examining the biggest movers in rank when comparing the currently used geometric mean HDI and the two proposed alternatives, all using the proposed income bounds. Table 12 lists the countries with the biggest increases in in position when comparing the two alternative HDI's to the currently used geometric mean HDI.

Table 12. Biggest Increases in Rank.

HDI_{geo} *vs.* HDI_R^C
HDI_{geo} *vs.* HDI_{zam}

Country	HDI_{geo}	Rank	HDI_{zam}	Rank	Δ Rank
Qatar	0.86	29	0.86	1	28
Kuwait	0.78	55	0.73	31	24
Gabon	0.69	110	0.54	88	22
Equatorial Guinea	0.58	138	0.47	118	20
UAE	0.82	43	0.75	24	19
Brunei Darussalam	0.84	32	0.78	14	18
Trinidad and Tobago	0.77	68	0.63	51	17
Suriname	0.71	99	0.55	82	17
Saint Kitts and Nevis	0.75	76	0.60	62	14
Luxembourg	0.88	21	0.80	8	13
Thailand	0.73	90	0.56	77	13

We see significant overlap in the top movers when comparing the HDI_R^C and HDI_{zam} indices to HDI_{geo} rankings. Three countries appearing on the HDI_R^C ranking as top movers but not on the HDI_{zam} side are in fact close to the biggest movers: Lichtenstein (+12; the twelfth largest gainer), Saudi Arabia (+11; the 15th largest gainer), and Oman (+11; the 16th largest gainer) would be the next entries on the HDI_{zam} list. Thailand, shown as a top gainer for HDI_{zam}, is the twentieth biggest gainer in position for HDI_R^C at +7 spots.

Now consider the largest decreases in rank for the HDI_R^C and HDI_{zam} indices, as compared to the HDI_{geo} rankings (Table 13).

Table 13 Biggest Decliners in Rank

HDI_{geo} vs. HDI_R^C

Country	HDI_{geo}	Rank	HDI_R^C	Rank	Δ Rank
New Zealand	0.897072	12	0.8	24	-12
Israel	0.881653	19	0.8	30	-11
Barbados	0.783574	52	0.7	63	-11
Cuba	0.76877	64	0.7	75	-11
Korea (Republic of)	0.883169	18	0.8	28	-10
Montenegro	0.795711	48	0.7	58	-10
Belarus	0.784388	51	0.7	61	-10
Iceland	0.902507	9	0.8	18	-9
Australia	0.918956	2	0.8	10	-8
Germany	0.905967	4	0.8	12	-8
Denmark	0.905023	5	0.8	13	-8
Slovenia	0.873706	25	0.8	33	-8
Greece	0.850541	30	0.8	38	-8
Bulgaria	0.781989	54	0.7	62	-8
Georgia	0.762182	70	0.7	78	-8
Ukraine	0.737492	83	0.7	91	-8

HDI_{geo} vs. HDI_{zam}

Country	HDI_{geo}	Rank	HDI_{zam}	Rank	Δ Rank
Cuba	0.76877	64	0.54	85	-21
Ukraine	0.737492	83	0.52	102	-19
Tonga	0.718086	96	0.49	111	-15
Georgia	0.762182	70	0.55	84	-14
Barbados	0.783574	52	0.6	65	-13
Armenia	0.736467	84	0.53	97	-13
Samoa	0.701057	103	0.48	116	-13
Montenegro	0.795711	48	0.61	60	-12
Belarus	0.784388	51	0.6	63	-12
Fiji	0.730028	89	0.52	101	-12
Moldova	0.696926	106	0.47	117	-11
New Zealand	0.897072	12	0.76	22	-10
Jamaica	0.723624	94	0.52	104	-10
Comoros	0.508394	159	0.3	169	-10
Kyrgyzstan	0.666268	119	0.43	128	-9
Kiribati	0.592763	135	0.37	144	-9

Again, although the exact change in rank differs, there is significant overlap in the countries which decrease in rank when comparing the HDI_R^C and HDI_{zam} indices to the HDI_{geo} rankings. Several countries appearing on the HDI_R^C table as top decliners but not on the HDI_{zam} side are very close to making the table: for HDI_{zam}, Israel is -9; Korea, Iceland, Slovenia, Greece are -8; Australia, Germany, Denmark and Bulgaria are -7.

Tonga, decreasing in rank by 15 spots for HDI_{zam}, drops 7 spots for HDI_R^C; Armenia and Fiji (-13 and –12 for

HDI_{zam}) drop 6 spots for HDI_R^C; Moldova and Jamaica drop 5 for HDI_R^C; Kyrgyzstan and Kiribati drop 1, and Comoros shows an increase in rank for HDI_R^C on one spot.

To this point, we see interesting movements that do not suggest any HDI formulation should be withdrawn from consideration for actual implementation, but do suggest that focusing on only one HDI formulation, like the geometric mean HDI, may lead to excluding information when evaluating wellbeing.

The final consideration is to directly compare HDI_R^C to HDI_{zam} (Tables 14 and 15).

Table 14 Biggest Increases in Rank when Comparing HDI_R^C to HDI_{zam}

Country	Rav	Rank	Zam	Rank	Δ Rank
Gabon	0.67	101	0.54	88	13
Swaziland	0.55	149	0.38	138	11
Lesotho	0.52	167	0.32	156	11
Côte d'Ivoire	0.50	174	0.30	163	11
Equatorial Guinea	0.61	128	0.47	118	10
Djibouti	0.51	172	0.31	162	10
South Africa	0.64	118	0.49	109	9
Sudan	0.52	166	0.32	157	9
Botswana	0.65809	104	0.525888	96	8
Angola	0.541005	154	0.367445	146	8
South Sudan	0.469774	184	0.256957	176	8

Table 15. Biggest Decliners in Rank when Comparing HDI_R^C to HDI_{zam}.

Country	Rav	Rank	Zam	Rank	Δ Rank
Comoros	0.53	156	0.30	169	-13
Kuwait	0.82	19	0.73	31	-12
Ukraine	0.67	91	0.52	102	-11
Madagascar	0.55	150	0.31	161	-11
Cuba	0.69	75	0.54	85	-10
Togo	0.53	161	0.29	171	-10
Liberia	0.51	173	0.24	183	-10
Malawi	0.53	163	0.28	172	-9
Congo (Democratic Rep. of the)	0.51	171	0.25	180	-9
Tonga	0.66	103	0.49	111	-8
Samoa	0.65	108	0.48	116	-8
Kyrgyzstan	0.63	120	0.43	128	-8
Kiribati	0.58	136	0.37	144	-8
Burundi	0.48	178	0.23	186	-8

Several of the countries on each list also appear in Tables 12 and 13. Taken together, Tables 12 through 15 show significant movement in a number of countries that appear in the bottom half of the current geometric mean HDI league table. These are precisely the countries the HDI aims to accurately assess.

3.3. Discussion

Implementing the currently used geometric mean HDI with 2016 data and revised income bounds of $50 and $129,916 (Qatar's 2016 income per capita) has an overall minor impact on country rankings, which we also find when we compare rankings at the old and new bounds for the generalized arithmetic mean (Ravallion (2012)) and the generalized geometric mean (Zambrano (2017)). The HDR should use the newer income bounds going forward given the inadequate rationale for using $100 and $75,000 discussed in Section 2.

Our results show the sensitivity of the HDI to the assumed income bounds, functional form, and the underlying core data. In particular, Tables 12 through 15 show significant movement in a number of countries from the bottom half of the current geometric mean HDI league table compared to the alternatives proposed by Ravallion (2012)'s and Zambrano (2017). These are the countries whose policymakers would be most interested in their country's ranking and its position relative to similar countries –geographical or otherwise – and to "aspirational" target countries. Our results support the findings of Ravallion (2012), which illustrated the disadvantageous downgrading of countries with lower income but more balanced health and education outcomes when comparing arithmetic and geometric mean HDIs. Given that it is not possible to determine the "true" development level of a particular country or ranking of countries to compare the results from different formulations of an HDI, it is limiting and misleading for HDR to only present a geometric mean HDI.

Nothing in our results suggest that either of the two alternative HDI formulations should be dismissed *a priori*. We suggest that HDR present country rankings generated by the two alternatives as well as the current HDI, along with the assumptions of each approach. Users can decide which assumptions are appropriate: whether core values are complements or substitutes, and if substitutes, to what extent. Users can also decide which index is more fully in line with their perception of the importance of marginal income increases. Descriptions and values of the free parameter r would be needed for both the Ravallion (2012a) and Zambrano (2017) approaches. The free parameter in the Zambrano (2017) index determines how income and life expectancy are traded off. Users will have to decide if the given tradeoff is in line with their views when considering this index. Finally, if users decide the three indices provide inconsistent results, they can use other data and tools to assess development level for that particular country.

4. Conclusion

Income's impact on the HDI is determined by the minimum and maximum values used when re-scaling the underlying income data into its dimension index and the functional form used to aggregate the health, education, and income dimensional indices into the HDI. The HDR currently uses income bounds of $100 and $75,000, and a geometric mean to combine the three dimensions. Two influential alternative HDI formulations put forth in the literature are the generalized arithmetic mean (Ravallion (2012)) and the generalized geometric mean (Zambrano (2017)).

Regarding the income bounds, the currently used minimum income of $100 has little theoretical support. Using a minimum income bound that is too high can unnecessarily distort the index for the poorest countries. The maximum income bound of $75,000 is not supported by recent research, which finds there is no satiation point for most people regarding income and well-being. Not capping income's contribution to well-being also captures the fullest expression of the capability approach. Using data for 2016, we investigate the impact of using new income bounds of $50 and $129,916 (Qatar's 2016 income per capita) on the currently used geometric mean and the alternatives proposed by Ravallion (2012a) and Zambrano (2017) and find an overall minor impact on country rankings. Given this minor impact along with the better rationales for the proposed income bounds, we recommend that going forward the HDR use $50 and the highest attained income per capita when formulating the HDI.

Whether looking at the overall change in rankings or movements of a specific country up or down the league table when comparing the three HDI formulations considered, there is no evidence to suggest any should be eliminated from consideration for actual implementation. We conclude that the best approach would be to calculate the current HDI as well as the two alternatives each year and provide the emphases of each approach with each set of rankings. Points to be conveyed include: Ravallion (2012)'s generalized arithmetic mean allows income to capture advances in human development unrelated to education and health; Zambrano (2017)'s generalized geometric mean penalizes countries with low values for education and health but high incomes compared to a scenario with more balanced achievements; and each of the three approaches varies in its treatment of income's diminishing marginal effects.

If the three methods produce similar results, there is no issue. If they are dissimilar, users can decide which index best represents their conception of well-being, or if they are unable to make this assessment, they can explore other data. This would be a more beneficial outcome than disseminating a single "one size fits all" HDI. Our suggestion is consistent with the overall theme of the capabilities approach to human development, whereby choice on what is important for wellbeing is given priority. It is also consistent with Ravallion (2012b)'s conclusion that more guidance should be given to users of "mashup indices" given the current lack of information provided on ranking robustness and implied weights on core values.

Regarding robustness, the sensitivity of the Ravallion (2012a) and Zambrano (2017) rankings to changes in the value of their free parameters is one area for further research. For example, in initial work, Kula (2019) finds that differences in rankings in the pre-2010 arithmetic mean HDI and HDR's current geometric mean HDI are smaller than for Zambrano (2017)'s generalized geometric mean evaluated at different values of its free parameter.

One critical area for further investigation is how to incorporate the Killingsworth et al (2023) finding of a non-linear relationship between income and well-being into the HDI: for 15-20% of the unhappiest people, increasing income increases well-being until a level of $100,000 is reached while for the 30% of people with the highest levels of well-being, increases in well-being accelerate with income increases above $100,000. In addition to implementation questions on appropriate income bounds and dimensional index aggregation function, this research will have to address several normative issues: is eliminating the current $75,000 cap on income enough to capture the "average" impact of income on well-being? Should greater weight be placed on income's contribution to the HDI – both level and marginal increases - for the worse-off 20%? Do the top 30% merit any attention? It is likely that multiple results, produced by various answers to these questions, will have to be provided so that users can decide which outcomes to utilize based on which assumptions are compatible with their conceptions of human development.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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