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Abstract

Gender Development Index and Gender Empowerment Measure are two gender-based indicators provided by the United Nations Development Program. Population share of the genders enter the formulation of these indicators in such a way that it favours the better performing gender. This can lead to further additions to 'missing women'. A correction is proposed to capture this anomaly. This alternative satisfies an axiom of Monotonicity with its two corollaries, that is, given attainments the measure maximizes at ideal sex ratio and vanishes when one of the genders becomes extinct. An empirical illustration by taking life expectancy data of countries is given.

Keywords: Ideality, Extinction, Index, Inequality, Sex-ratio
JEL Codes: D63, J16, I31, O15

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1. Introduction

United Nations Development Program (UNDP) measures gender sensitive human development through two indicators, namely, Gender Development Index (GDI) and Gender Empowerment Measure (GEM). These indicators measure the *overall* achievement taking *note* of inequality between the two genders. GDI adjusts the average development, measured by Human Development Index (HDI), to reflect the gender inequalities in the three dimensions of health, education and ability to achieve a decent standard of living. GEM captures the inequalities in opportunities between men and women in the three dimensions of political participation, economic participation and power over economic resources. For each dimension of GDI and GEM, an equally distributed equivalent index, X_{ede} is computed by combining female and male indices in a way that penalizes differences in achievement between the two genders.[2] The population-proportion of female and male enter into the formulation of X_{ede} as weights to female and male achievements respectively, like the case of weighted mean. This follows that for a given level of female and male achievements, a rise in the population proportion of the gender with a higher level of achievement will result in higher X_{ede}. It leads to rewarding of countries having imbalanced population-proportion biased towards the higher performing gender as shown in the following example.

The life expectancy indices of female and male for United Arab Emirates (UAE) are 0.892 and 0.905 respectively, and that of United Kingdom (UK) are 0.895 and 0.903.[3] In terms of X_{ede} of life expectancy, UAE and UK score 0.901 and 0.899 respectively and their ranks are 19 and 21 in the world.[4] This indicates both the countries are close to each other in terms of health dimension of GDI. However, in terms of population-proportion, male/female for UAE is 0.68/0.32 and that of UK is 0.49/0.51. In fact UAE, with more than two males for

[2] For the expression of X_{ede}, see Section 2 of this paper. The formula for female and male indices is: Index=(actual-minimum)/(maximum-minimum).

[3] Life expectancy index is computed by positing a minimum and maximum. The minimum and maximum values for life expectancy at birth (in years) for female are 27.5 and 87.5 and for male, the corresponding figures are 82.5 and 22.5 respectively.

[4] The ranks for 173 countries, out of the total 177 countries listed in Human Development Report (HDR) 2007/2008 (UNDP, 2007), are computed on the basis of X_{ede} of life expectancy. Life expectancy data for four countries Antigua and Barbuda, Dominica, Saint Kitts and Nevis, and Seychelles are not available.

every female, has the most skewed sex ratio in the world. UK, on the contrary, has a balanced sex ratio. Also, the difference in life expectancy indices of female and male for UK is 0.008 which is less than that of UAE, which is 0.013. Yet, UAE ends up fetching a better rank than UK. Instead of being penalized for imbalanced population-proportion, UAE gets rewarded as the imbalance favours male which has higher life expectancy.

The UAE story repeats for countries like Quatar, Kuwait, Bahrain, Oman, Saudi Arabia. Their imbalanced population-proportion acts to their advantage. This anomaly affects all equally distributed indices used in the measure different dimensions of GDI and GEM. These indices signal countries to favour the higher performing gender and neglect the gender which is lower in performance (typically female). This leads to further additions to 'missing women'.[5] For example, a country, where female literacy is lower than male can improve its education dimension of GDI, by improving the male/female ratio; through female infanticide, abandonment of newborn girls, and neglect of daughters. So, as gender sensitive development indicators, the signal of GDI and GEM is counter intuitive. Ideally, these indicators should signal countries to correct their gender imbalances in population-proportion, rather than to distort it further.

This paper revisits the gender-based indicators and proposes a correction so as to account for population-proportion of female and male in such a way that countries farther to the ideal sex ratio are penalized. An axiom of Monotonicity, with its two corollaries: Ideality and Extinction, is posited to characterize the measure. To demonstrate the advantage of the proposed measure, equally distributed life expectancy index has been used.[6] The paper makes use of life expectancy data from the latest HDR (UNDP, 2007) and population data from United Nations (UN, 2008).

2. Conventional measure

For a pair of female and male achievements (X_f, X_m), equally distributed equivalent index, X_{ede} is given by general formula

$$\left.\begin{aligned} X_{ede} &= [(p_f\,(X_f)^{(1-\varepsilon)} + p_m(X_m)^{(1-\varepsilon)}]^{1/(1-\varepsilon)} \quad \text{where } \varepsilon\geq 0 \;\&\; \varepsilon\neq 1; \\ X_{ede} &= (X_f)^{Pf}\,(X_m)^{Pm} \quad \text{for } \varepsilon=1 \end{aligned}\right\} \qquad (1)$$

[5] 'Missing women' is the term coined by Amartya Sen (Sen, 1992) to describe the terrible deficit of women in substantial part of Asia and North Africa due to sex bias in relative care. This term is used in the present paper as an analogy to describe disadvantaged gender which can be male as well. For instance, a country prone to war will have female life expectancy relatively higher due to decimation of men fighting war.

[6] The composite indices GDI and GEM are not recalculated here, as aggregated values will be inconclusive on the effect on individual dimensions.

where, p_f and p_m are proportion of female and male respectively such that $p_m+p_f=1$ and ε is the aversion to inequality. For moderate penalty, the value 2 is used for ε (UNDP, 2007). With $\varepsilon=2$, X_{ede} is the harmonic mean of X_f and X_m, given by

$$X_{ede} = [(p_f (X_f)^{(-1)} + p_m(X_m)^{(-1)}]^{(-1)} \quad (2)$$

The properties of X_{ede} are listed in Appendix 1.[7] Given (X_f, X_m), X_{ede} varies between X_f to X_m as p_f, p_m vary. Fig.1 plots this variation, with $X_f=0.3$ and $X_m=0.8$. A rise in the population proportion of the gender with higher level of achievement (here male, as $X_m>X_f$) results in higher X_{ede}. The boundary conditions are at $p_m=0$, $X_{ede}=X_f$ and at $p_m=1$, $X_{ede}=X_m$. All this is counter intuitive for a development indicator sensitive to gender. How can it boils down to the achievement of one gender when the other gets extinct! Does existence or extinction of genders or sex-ratio has nothing to do with gender-development or gender-equity!

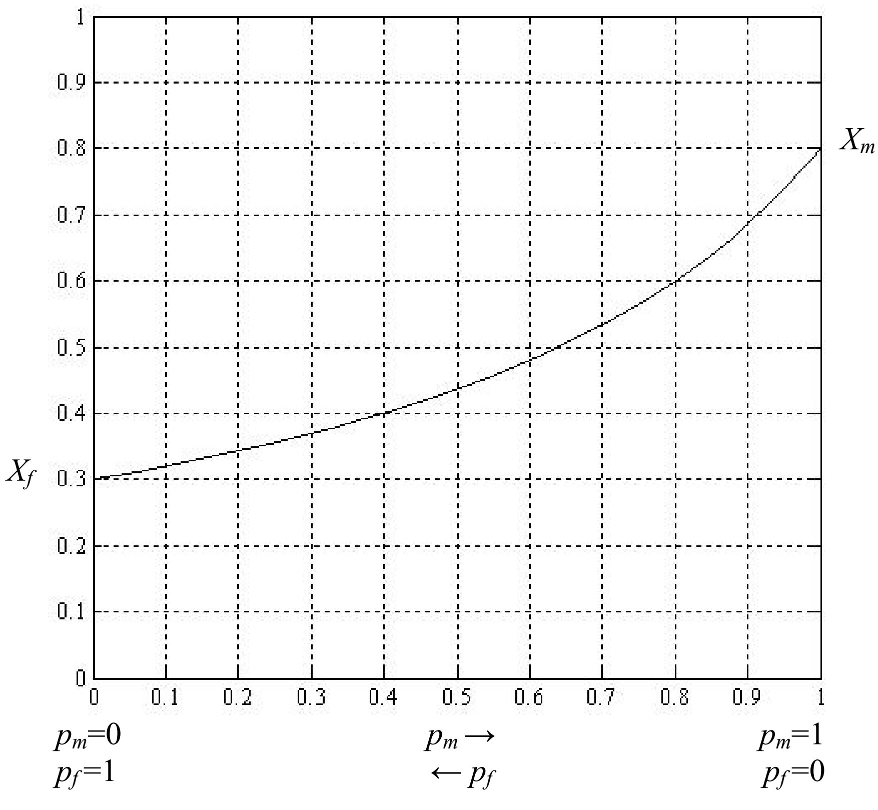

Fig. 1. Variation of X_{ede} with population proportion (p_m, p_f)

Since rise in the population proportion of higher performing gender leads to higher X_{ede}, a country gets rewarded for deviation from the ideal sex ratio half of the time i.e. when

[7] These properties are noted in Anand and Sen (2003), some in the text, and some in Appendices. For details of the proof of the properties, see the same paper. Here, they are collated together in a tabular form for comparison of the present measure with the proposed one.

the deviation favours the advantaged gender. The irony is that instead of being penalized for not able to protect the gender, a country maximizes its X_{ede} when the lower performing gender gets extinct. So, X_{ede}, and in turn the measures based on X_{ede} do not signal countries to maintain population-proportion of female and male at a balanced state. The gulf countries, for instance, do not get any signal to have policies to balance their sex ratio. Rather they would prefer a more skewed sex ratio biased towards men, as it leads to higher value of X_{ede}. The signal of conventional measure of X_{ede} is: 'more achievement, more proportion – the better'. The correct signal is: 'more achievement, ideal proportion – the better'. The following section briefs on ideal proportions of female (p_{fi}) and male (p_{mi}) in human population.

3. Ideal sex ratio for human population

The actual average sex ratio of entire world population is 1.01 (UN, 2008).[8] However, the value of ideal sex ratio is under debate and may vary with regions and races. The sex ratio of a population depends on three factors: the sex ratio at birth, differential mortality rates between the sexes at different ages, and losses and gains through migration (Coale, 1991). In the absence of manipulation, the sex ratio at birth is remarkably consistent across human populations, at 1.05 to 1.07 (Coale, 1991, Campbell, 2001). Although sex ratio at birth favors males, differential gender mortality favors females (Teitelbaum, 1970; Sen, 1992, Waldron 1993). Higher life expectancy in females tends to even out the sex ratio in adult population, with male excess among the young and female excess among the old (Klasen and Wink, 2003). But, manipulation at birth manifested by sex-selective abortion, and neglect and abandonment of female children, and international migration characterized by shifting of male population affect sex-ratio. However, like other species, natural human sex ratio is approximately unity and deviation is a threat to the stability and security of the society (Zeng *et al*, 1993, Park and Cho, 2003, Hudson and Den Boer, 2004). For simplicity, unity sex ratio i.e. equal proportion of female and male (p_{fi}=p_{mi}=0.5) is used in this paper for illustrations.

4. Axiom of Monotonicity

This section presents Monotonicity property that a measure of equally distributed equivalent achievement should satisfy with respect to sex ratio.

[8] Sex ratio is expressed in this paper as (male population)/(female population)

Axiom of *Monotonicity*:[9] Given the achievement level of two genders, the equally distributed equivalent achievement, increases as population approaches to its ideal sex ratio. Mathematically, given X_f, X_m ($0 \leq X_f, X_m \leq 1$), X_{ede} increases as $(p_m/p_f) \rightarrow (p_{mi}/p_{fi})$. Referring to Fig. 1, axiom of Monotonicity requires X_{ede} to have a positive and negative slope for $p_m < p_{mi}$ and $p_m > p_{mi}$ respectively. Two corollaries of Monotonicity are axioms of Ideality and Extinction.

Axiom of *Ideality*: Given the achievement level of two genders, the equally distributed equivalent achievement maximizes at the ideal sex ratio. Mathematically, given X_f, X_m ($0 \leq X_f, X_m \leq 1$), $X_{ede} = (X_{ede})_{\max}$ for $(p_m/p_f) = (p_{mi}/p_{fi})$. Referring to Fig. 1, axiom of Ideality requires X_{ede} to maximize at ideal proportion of female and male (say $p_{fi} = p_{mi} = 0.5$).[10]

Axiom of *Extinction*: Irrespective of achievement levels of two genders, if any of the genders goes extinct, the equally distributed equivalent achievement reduces to minimum possible value i.e. 0. Mathematically, for any X_f, X_m ($0 \leq X_f, X_m \leq 1$) $X_{ede} = 0$ if $p_f = 0$ or $p_m = 0$. [11] Referring to Fig. 1, axiom of Ideality requires X_{ede} to be 0 at points $p_m = 0$ and $p_m = 1$.

5. Proposed measure

The genesis of the weakness of the conventional measure lies with the absence of penalty for deviating from ideal sex ratio. The conventional measure does take note of inequality in the achievements of the two genders (i.e. between X_f and X_m) in different dimensions like health, education; but inequality in proportion of population (i.e. between p_f and p_m) is not accounted.[12] Imposition of axiom of Monotonicity will make the measure sensitive to deviation from ideal sex ratio. Accordingly, a new measure of equally distributed equivalent achievement, ${}^{n}X_{ede}$ is proposed.

$$\left.\begin{aligned} {}^{n}X_{ede} &= [p/p_i]^{\theta}[p_f (X_f)^{(1-\varepsilon)} + p_m (X_m)^{(1-\varepsilon)}]^{1/(1-\varepsilon)} && \text{for } \varepsilon \geq 0, \theta \geq 0 \ \& \ \varepsilon \neq 1 \\ {}^{n}X_{ede} &= [p/p_i]^{\theta}(X_f)^{Pf}(X_m)^{Pm} && \text{for } \varepsilon = 1, \theta \geq 0 \end{aligned}\right\} \quad (3)$$

where p and p_i are the actual and ideal proportion of that gender whose actual population is less than or equal to the ideal. The proposed measure is different from the conventional one in the first term, i.e. the penalty factor, which takes note of the deviation from ideal sex ratio.

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[9] Monotonicity, here means in a strong sense.

[10] It is not compulsory to assume $p_{fi} = p_{mi} = 0.5$. The debate of 'what should be the ideal sex ratio' is out of the scope of the paper. However, axiom of Ideality simply says, X_{ede} must maximize at given ideal, p_{fi}, p_{mi}

[11] In general, axiom of Extinction is applicable only to the gender whose ideal proportion of population is non zero. Let us consider a hypothetical specie having ideal population proportion for female and male as 1:0. Here $p_m = 0$ is the condition for Ideality, so X_{ede} maximises. The axiom of Extinction is applicable only to female gender i.e. at $p_f = 0$

[12] Under the assumption of unity ideal sex ratio, deviation from ideal can be captured as difference of population-proportion of female and male.

The factor is powered by θ, which controls the aversion to this deviation. Larger the θ, smaller is the ${}^{n}X_{ede}$.[13] At θ=0, ${}^{n}X_{ede}$ reduces to X_{ede} showing no concern for deviation from ideal sex ratio. For θ>0, the penalty factor gets actuated. The axiom of Extinction gets satisfied for any θ>0. This signifies, once ${}^{n}X_{ede}$ is sensitive towards deviation from ideal sex ratio, howsoever small the sensitivity may be; it would reduce to zero if one of the genders goes extinct. This is rational, as any gender sensitive development indicator would penalize a society most severely where one of the genders could not survive in the first place, let alone develop.

For a moderate penalty on gender inequality in achievement i.e. ε=2, the axiom of Monotonicity is satisfied for $\theta \geq 1$.[14] So, for ε=2, 1 is the minimum value of θ for which Monotonicity with both of its corollaries are satisfied; hence 1 is chosen for θ. For ε=2 and θ=1, equation (3) reduces to

$$ {}^{n}X_{ede} = [p/p_i][(p_f\,(X_f)^{(-1)} + p_m(X_m)^{(-1)}]^{(-1)} \qquad (4)$$

The propoerties of ${}^{n}X_{ede}$ are listed vis-à-vis X_{ede} in Appendix 1.

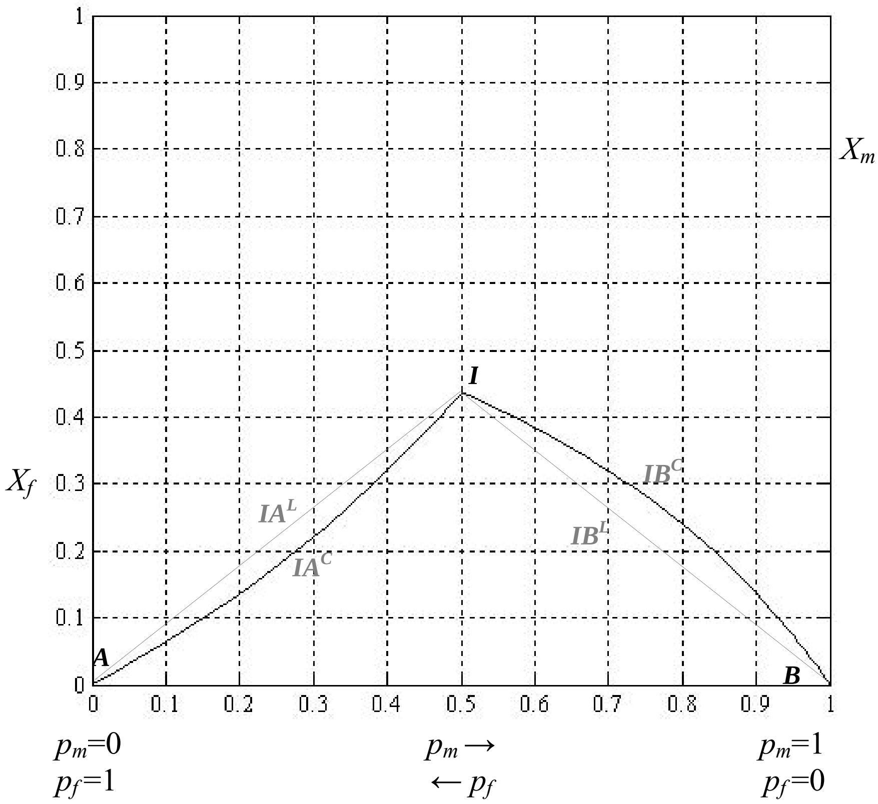

Fig. 2. Variation of ${}^{n}X_{ede}$ with population proportion (p_m, p_f)

[13] From Eq. (1) and Eq. (3) ${}^{n}X_{ede}=[p/p_i]^{\theta}(X_{ede})$, $(\partial({}^{n}X_{ede})/\partial\theta)=(X_{ede})[p/p_i]^{\theta}\ln(p/p_i)$. Since $(p/p_i)\leq 1$, $(\partial({}^{n}X_{ede})/\partial\theta)\leq 0$

[14] Proof is in Appendix 2.

Fig. 2 plots ${}^{n}X_{ede}$ against p_m and p_f for same values of X_f and X_m as in Fig. 1 i.e. X_f=0.3, and X_m=0.8. ${}^{n}X_{ede}$ is 0 at exitnction conditions (p_m=0 or p_m=1) and maximizes at ideal sex ratio (p_m/p_f=p_{mi}/p_{fi}=0.5/0.5). The maximum value, $({}^{n}X_{ede})_{\max}$ is the harmonic mean of X_f=0.3 and X_m=0.8, which coincides with the value of X_{ede} at ideal sex ratio as the penalty factor reduces to 1. For $p_m<p_{mi}$ the profile is represented by curve IA^C and for $p_m>p_{mi}$, curve IB^C. The positive and negative slope of IA^C and IB^C respectively, validates the axiom of Monotonicity. The following propositions further characterize ${}^{n}X_{ede}$.

Proposition. *The equally distributed equivalent achievement has a convex-decrease for fall in proportion of higher performing gender from ideal and a concave-decrease for lower performing gender.*[15]

In Fig. 2, since $X_m>X_f$, IA^C and IB^C have convex and convex profiles respectively. The straight lines IA^L, IB^L represent the profile of ${}^{n}X_{ede}$ for fall in p_m and p_{fi} respectively under the condition of gender indistinguishability, i.e. both the genders are at same level of achievement, hence are not distinguishable from the achievement point of view. Substituting, X_f=X_m=X in Eq. (4) we get the linear relationship between ${}^{n}X_{ede}$ and population-proportion.

$$ {}^{n}X_{ede} = [p/p_i]X \tag{5} $$

So, the common achievement X coincides with $({}^{n}X_{ede})_{\max}$. Under this condition of gender indistinguishability, for p_{mi}=p_{fi}, the profiles of ${}^{n}X_{ede}$ at both sides of ideal are symmetric. IA^L, IB^L are a pair of such symmetric lines corresponding to X=(0.48/1.1) i.e. harmonic mean of X_f=0.3 and X_m=0.8.

IA^C is below IA^L and IB^C is above IB^L. At a given population-proportion, a shift from IA^L to IA^C indicate a movement from gender indistinguishability, where all the population are at common achievement level, to a state where less than the ideal share population move to higher achievement level and rest move to a lower achievement level. Hence the overall achievement will fall. In case of movement from IB^L to IB^C more than the ideal share population move to higher achievement level leading to a improvement in overall achievement. This translates to the following lemma.[16]

Lemma 1. *For any given population-proportion between ideality and extinction, when higher performing gender has more (less) share than ideal share, the equally distributed equivalent achievement is higher (lower) than the condition of gender indistinguishability.*

On the basis of the above lemma, for p_{fi}=p_{mi}, it is straight forward to show that for a given population-proportion the equally distributed equivalent achievement is higher when

[15] Proof for ε=2, θ=1, is in Appendix 3
[16] Proof for ε=2, θ=1, is in Appendix 4

higher performing gender has more share than the case when the proportion is swapped between the two. Also, for p_{fi}=p_{mi}, magnitude wise the slope of IA^C is higher than that of IB^C at ideal. This is obvious from the fact that at equal population-proportion of two groups, fall of proportion of the higher quality group entails a greater loss to the society than the lower quality one. This leads to the following lemma.

Lemma 2. *For equal population-proportion of genders at ideal the equally distributed equivalent achievement decreases at a faster rate at ideal when population proportion falls for the higher performing gender than for the lower one. For condition of gender indistinguishability, the rate of decrease lies in between.*

The proof of the above is straight forward from the fact that IA^C and IB^C are convex and concave respectively lying below and above of IA^L and IB^L which are symmetric under unity ideal sex ratio.

6. Applying the new measure to equally distributed life expectancy index

Taking female and male life expectancy data for countries of the year 2005 from HDR *2007-2008* (UNDP 2007) and their population-proportion data from Population Division, Department of Economic and Social Affairs of United Nations (UN, 2008) ranks of the countries are obtained on the basis of X_{ede} and ${}^{n}X_{ede}$ (Appendix 5). A value of p_{mi}=p_{fi}=0.5 (i.e. sex ratio 1:1) is used for the purpose. The aversion parameters are taken as θ=1 and ε=2. The difference in ranks indicates that a negative (positive) value implies a worse (better) performance of the country with the proposed measure when compared with the conventional one. The last column is population-proportion difference expressed as female share of population to male share, a negative value showing where male share is higher. The countries those have lost rank under new measure are referred to as losers. Similarly, those that moved up in the ranks are referred to as gainers. Following are some observations.

Table 1: Biggest Losers

COUNTRY	Life Exp. Index of Female	Life Exp. Index of Male	Sex ratio (males/ females)	Conventional Rank	Sex ratio adjusted Rank	Rank Diff.	Gender Prop. Diff.
United Arab Emirates	0.892	0.905	2.137	19	129	-110	-0.363
Qatar	0.805	0.868	2.064	41	134	-93	-0.347
Kuwait	0.868	0.887	1.500	33	101	-68	-0.200
Bahrain	0.825	0.857	1.323	43	93	-50	-0.139
Oman	0.820	0.852	1.284	47	87	-40	-0.124
Saudi Arabia	0.785	0.797	1.172	66	90	-24	-0.079

The six gulf countries, UAE, Qatar, Kuwait, Bahrain, Oman and Saudi Arabia; stand out as biggest looser as per the proposed measure of equally distributed life expectancy index. These six countries have the dubious distinction of world's top rankers in terms of unbalanced sex ratio biased towards male. Table 1 illustrates their case. In all these countries, male life expectancy index is more than female. Since men outnumber women by large margins, these countries get the undue advantage under the conventional measure. In the new measure they lost rank because of the penalty for deviation from ideal sex ratio.

Table 2: Some selected cases for comparison

COUNTRY	Life Exp. Index of Female	Life Exp. Index of Male	Sex ratio (males/ females)	Conventional Rank	Sex ratio adjusted Rank	Rank Diff.	Gender Prop. Diff.
Cuba	0.872	0.888	1.000	32	22	10	-0.001
Kuwait	0.868	0.887	1.500	33	101	-68	-0.200
Nicaragua	0.792	0.775	1.000	74	58	16	0.001
Latvia	0.830	0.733	0.842	75	97	-22	0.085
Iceland	0.927	0.957	1.000	3	1	2	0.000
Japan	0.970	0.937	0.957	1	2	-1	0.023

Table 2 gives a comparison between some selected gainers and losers. Cuba has less inequality in life expectancy for female and male than Kuwait. But Kuwait has managed to fetch a similar rank as Cuba because of its male biased sex ratio; so a higher weight of male performance contributing to the higher final value. However, under the new measure Cuba performed relatively better for its balanced sex ratio. Kuwait, on the contrary, having three males per two females lost its earlier rank by 68 positions.

It is not always true that men fared better than women. Male have a greater tendency to engage in risk behaviors and violence, thus increasing their risk of premature mortality (Waldron, 1993). Lativia is an example where not only females have more life expectancy, but also they are higher in population-proportion. This is the precise reason for which Lativia occupied a rank next to Nicaragua, which is much more equal in terms life expectancy across gender but also has a balanced sex ratio. Under the new measure, Lativia regresses to a lower rank on account of a biased sex ratio towards female, whereas Nicaragua improved its positions.

Japan tops the list under conventional measure, but when penalty for deviation from ideal sex ratio is introduced, Japan looses its rank to Iceland. As seen from the table Japan's sex ratio is biased towards females (only 957 males for 1000 females) and females have higher life expectancy index. In fact, Japanese women live the longest in the world. However, Japan got penalized under the new measure whereas Iceland, with equal proportion of males and females (1:1), does not get affected by the penalty.

7. Conclusion

The present gender equity-sensitive development indicators suffer from the limitation that countries with unbalanced sex ratio get rewarded where sex ratio is biased towards the higher performing gender. This paper questions the rationality of such indicators which take note of, for instance, inequality in life expectancy without consideration of the 'life' itself! An axiom of Monotonicity is posited so that equally distributed equivalent achievement increases as the population closes to ideal sex ratio. Two corollaries; axiom of Ideality and axiom of Extinction make the measure respectively to maximize at ideal sex ratio and to reduce to zero when one of the genders gets extinct. A new measure has been proposed which brings in a penalty factor to capture the deviation from ideal sex ratio. The new measure has a convex-decrease for fall in proportion of higher performing gender from ideal and a concave-decrease for lower performing one. Under this proposed measure, gulf countries get penalized for their unnaturally unbalanced sex ratio biased towards male. Countries with higher level of achievement, lower disparity between male and female and population-proportion closer to ideal sex ratio get rewarded. Unlike the conventional measure, the new measure gives appropriate signal to countries to correct for the 'Missing Women'. The proposed measure is more flexible with different handles of aversion to proportion-inequality and achievement-inequality. Though a uniform ideal sex ratio of 1:1 is used for the present analysis, the formulation is generic enough to consider different ideal sex ratios for different age group, countries, regions, and races. Moreover, the new measure can be used to find equally distributed equivalent achievement between two groups other than gender where a desired proportion of the two groups are postulated. For instance, the equally distributed equivalent index for education calculated for BPL (below poverty line) and APL (above poverty line) groups (note the desired population-proportion of BPL to APL is 0:1) using the proposed measure not only takes note of the inequality in achievement in education between the two gender, but also rewards a society who have higher proportion of people as APL However, the proposed measure is applicable to population of two groups. As a future scope, similar measures for more than two groups can be conceptualized.

Appendix 1

Comparison of properties of conventional measure (X_{ede}) and proposed measure ($^{n}X_{ede}$)	
(i) $\min(X_f, X_m) \leq X_{ede} \leq \max(X_f, X_m)$	$0 \leq {}^{n}X_{ede} \leq \max({}^{n}X_{ede})$ where $\max({}^{n}X_{ede})=[(p_{fi}(X_f)^{(-1)}+p_{mi}(X_m)^{(-1)}]^{(-1)}$ =harmonic mean of X_f and X_m at p_{mi}, p_{fi}. This property qualifies the axiom of Ideality and Extinction.
(ii) at ε=0, $X_{ede}=X^a$ i.e. arithmetic mean of achievement of population; for ε>0, $X_{ede}<X^a$	at ε=0, $^{n}X_{ede}=[p/p_i]^{\theta}X^a$. When $p=p_i$; $^{n}X_{ede}=X^a$ For ε>0, $^{n}X_{ede}<[p/p_i]^{\theta}X^a \leq X^a$
(iii) larger the ε, smaller is X_{ede}	(iii) larger the ε, smaller is X_{ede}; larger θ smaller is X_{ede}.
(iv) $X_{ede} \rightarrow \min(X_f, X_m)$ as $\varepsilon \rightarrow \infty$.[17]	(iv) $^{n}X_{ede} \rightarrow [p/p_i]^{\theta}[\min(X_f, X_m)]$ as $\varepsilon \rightarrow \infty$. When $\varepsilon \rightarrow \infty$ and $p \rightarrow p_i$; $^{n}X_{ede} \rightarrow \min(X_f, X_m)$
(v) X_{ede} is monotonic increasing in both X_f and X_m, the increase is at diminishing rate.[18]	Property remains same for $^{n}X_{ede}$.
(vi) a unit increase in performance for the gender with higher population but lower level of performance is more valuable socially (higher X_{ede}) than the unit increase in performance for the other gender.	Property remains same for $^{n}X_{ede}$.
(vii) a rise in the population proportion of a sub group with higher level of achievement will result higher X_{ede}.	closer the proportion population to the ideal higher is $^{n}X_{ede}$. This property validates axiom of Monotonicity.
(viii) more concave the underlining form of X_{ede}, smaller is X_{ede}. The present underlining form of X_{ede} is $(1/(1-\varepsilon))X^{(1-\varepsilon)}$.	Property remains same for $^{n}X_{ede}$
(ix) the relative gender equality index, E is maximum for $X_f=X_m$ and $\max(E)=1$.[19]	the relative gender equality index, E is maximum for $X_f=X_m$ and $\max(E)= [p/p_i]^{\theta}$. When $p \rightarrow p_i$; $\max(E) \rightarrow 1$.
(x) for equality of proportion, ($p_f=p_m$) E is symmetric in X_f and X_m. E $\rightarrow 0$, if $(X_f/X_m) \rightarrow 0$ or $(X_f/X_m) \rightarrow \infty$.	Property remains same for $^{n}X_{ede}$

[17] This resembles to Rawlsian maximin situation where achievement is judged purely by the achievement of the worst off group.

[18] The diminishing rate of increase is not valid for all concave functions; but for standard cases like constant relative inequality aversion ($X_{ede} = (1/(1-\varepsilon))X^{(1-\varepsilon)}$) and constant absolute inequality aversion ($X_{ede} = -e^{\gamma x}$) (Anand and Sen, 2003)

[19] $E = (X_{ede} / X^a)$ is the ratio of the (1-ε) average to the arithmetic mean (AM). The result is intuitive as (1-ε) average of two numbers is same as AM only when the numbers are equal; in all other cases (1-ε) average < AM.

Appendix 2

Without loss of generality (wlog), Eq. (3) can be expressed in p_m, (p_f is substituted by (1-p_m))

$^nX_{ede} = [p_m/p_{mi}]^{\theta}[(1-p_m)(X_f)^{(1-\varepsilon)}+ p_m(X_m)^{(1-\varepsilon)}]^{1/(1-\varepsilon)}$ for $\varepsilon\geq 0, \theta\geq 0$ & $\varepsilon\neq 1$ (6)

Note the above equation is valid for $p_m\leq p_{mi}$. For $p_m>p_{mi}$ the penalty term changes to $[p_f/p_{fi}]^{\theta}=[(1-p_m)/(1-p_{mi})]^{\theta}$. To satisfy the axiom of Monotonicity we need to prove $(\partial(^nX_{ede})/\partial p_m)>0$ for $p_m\leq p_{mi}$ and $(\partial(^nX_{ede})/\partial p_m)<0$ for $p_m>p_{mi}$. Differentiating Eq. (6),

$$\frac{\partial(^nX_{ede})}{\partial p_m} = \left(\frac{p_m}{p_{mi}}\right)^{\theta}\frac{1}{(1-\varepsilon)}\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)^{\frac{\varepsilon}{(1-\varepsilon)}}\left(X_m^{(1-\varepsilon)} - X_f^{(1-\varepsilon)}\right)$$

$$+\theta\left(\frac{p_m}{p_{mi}}\right)^{\theta-1}\left(\frac{1}{p_{mi}}\right)\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)^{\frac{1}{(1-\varepsilon)}}$$

$$=\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)^{\frac{\varepsilon}{(1-\varepsilon)}}\frac{p_m^{\theta-1}}{p_{mi}^{\theta}}\left(\left(\frac{p_m}{(1-\varepsilon)}\left(X_m^{(1-\varepsilon)} - X_f^{(1-\varepsilon)}\right)\right) + \theta\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)\right)$$

$$=\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)^{\frac{\varepsilon}{(1-\varepsilon)}}\frac{p_m^{\theta-1}}{p_{mi}^{\theta}}\left(X_m^{(1-\varepsilon)}\left(\theta\, p_m + \frac{p_m}{(1-\varepsilon)}\right) + X_f^{(1-\varepsilon)}\left(\theta(1-p_m) - \frac{p_m}{(1-\varepsilon)}\right)\right)$$

$$=\left((1-p_m)X_f^{(1-\varepsilon)} + p_mX_m^{(1-\varepsilon)}\right)^{\frac{\varepsilon}{(1-\varepsilon)}}\frac{p_m^{\theta-1}}{p_{mi}^{\theta}}\left(X_m^{(1-\varepsilon)}C_m + X_f^{(1-\varepsilon)}C_f\right)$$

$$\textit{where}\quad C_m = \left(\theta\, p_m + \frac{p_m}{(1-\varepsilon)}\right) \textit{and}\ C_f = \left(\theta(1-p_m) - \frac{p_m}{(1-\varepsilon)}\right)$$

for $\varepsilon<1$, $C_m>0$. So, for $(\partial(^nX_{ede})/\partial p_m)>0$ for all values of X_f, X_m, $C_f\geq 0$, implies

$$\theta(1-p_m) \geq \frac{p_m}{(1-\varepsilon)} \Rightarrow \theta \geq \frac{p_m}{(1-p_m)}\frac{1}{(1-\varepsilon)} \Rightarrow \theta \geq \frac{p_m}{p_f}\frac{1}{(1-\varepsilon)}$$

for $\varepsilon=0.5$, $p_m=0.5$, $\theta\geq 2$; so θ should be at least 2 to satisfy the axiom of Monotonicity.

for $\varepsilon>1$, $C_f>0$. So, for $(\partial(^nX_{ede})/\partial p_m)>0$, for all values of X_f, X_m, $C_m\geq 0$, implies

$$\theta\, p_m \geq \frac{p_m}{(\varepsilon-1)} \Rightarrow \theta \geq \frac{1}{(\varepsilon-1)}$$

for $\varepsilon=2$, $\theta\geq 1$; so θ to be at least 1 to satisfy the axiom of Monotonicity for $p_m\leq p_{mi}$. Similarly, for $p_m>p_{mi}$, for $\varepsilon=2$ it can be shown θ to be at least 1 to satisfy $(\partial(^nX_{ede})/\partial p_m)<0$.

Appendix 3

Wlog, for $p_m\leq p_{mi}$ Eq. (3) can be expressed in p_m (p_f is substituted by (1-p_m)). For $\varepsilon=2$

$$^nX_{ede} = [p_m/p_{mi}]^{\theta}[(1-p_m)(X_f)^{(-1)}+ p_m(X_m)^{(-1)}]^{(-1)}$$

Differentiating with respect to p_m

$$\frac{\partial({}^{n}X_{ede})}{\partial p_m} = \theta \frac{p_m^{\theta-1}}{p_{mi}^{\theta}}\left((1-p_m)X_f^{-1} + p_m X_m^{-1}\right)^{-1} + \left(\frac{p_m}{p_{mi}}\right)^{\theta}(-1)\left((1-p_m)X_f^{-1} + p_m X_m^{-1}\right)^{-2}(X_m^{-1} - X_f^{-1})$$

$$= \frac{p_m^{\theta-1}}{p_{mi}^{\theta}}\left((1-p_m)X_f^{-1} + p_m X_m^{-1}\right)^{-1}\left(\theta - \frac{p_m(X_f - X_m)}{p_m(X_f - X_m) + X_m}\right)$$

Differentiating again and simplifying,

$$\frac{\partial^2({}^{n}X_{ede})}{\partial p_m^{2}} = \frac{p_m^{\theta-2}}{p_{mi}^{\theta}}\left((1-p_m)X_f^{-1} + p_m X_m^{-1}\right)^{-1}$$

$$\left(\left(\theta - 1 - \frac{p_m(X_f - X_m)}{p_m(X_f - X_m) + X_m}\right)\left(\theta - \frac{p_m(X_f - X_m)}{p_m(X_f - X_m) + X_m}\right) - \frac{p_m x_m(X_f - X_m)}{\left(p_m(X_f - X_m) + X_m\right)^2}\right)$$

For θ=1, $\frac{\partial^2({}^{n}X_{ede})}{\partial p_m^{2}} = \frac{p_m^{\theta-2}}{p_{mi}^{\theta}}\left((1-p_m)X_f^{-1} + p_m X_m^{-1}\right)^{-1}(-2)\frac{p_m X_m(X_f - X_m)}{\left(p_m(X_f - X_m) + X_m\right)^2}$

Hence, for $X_f>X_m$, $\frac{\partial^2({}^{n}X_{ede})}{\partial p_m^{2}}<0$, the increase slope is diminishing i.e. the profile is concave.

For $X_f<X_m$, $\frac{\partial^2({}^{n}X_{ede})}{\partial p_m^{2}}>0$, the slope is convex. Similar proofs can be obtained for $p_m>p_{mi}$.

Appendix 4

Wlog, lets consider $X_m>X_f$. For $p_m<p_{mi}$ we need to prove

$$[(p_m/p_{mi})\{(1-p_m)(X_f)^{(-1)}+ p_m(X_m)^{(-1)}\}^{(-1)}] < [(p_m/p_{mi})X]$$

where X=Harmonic Mean of X_f and X_m at condition of Ideality $p_m= p_{mi}$, $p_f=p_{fi}$. Replacing the value of X in the above equation, the proof requires,

$$[(p_m/p_{mi})\{(1-p_m)(X_f)^{(-1)}+ p_m(X_m)^{(-1)}\}^{(-1)}]<[(p_m/p_{mi})\{(1-p_{mi})(X_f)^{(-1)}+ p_{mi}(X_m)^{(-1)}\}^{(-1)}]$$

Cancelling the common factor (p_m/p_{mi}), the proof requires,

$$[\{(1-p_m)(X_f)^{(-1)}+ p_m(X_m)^{(-1)}\}^{(-1)}]<[\{(1-p_{mi})(X_f)^{(-1)}+ p_{mi}(X_m)^{(-1)}\}^{(-1)}]$$

The above inequality is true from property (vii) of X_{ede} as mentioned in Appendix 1. Also this can be seen from Fig. 1 (in the text) where for $p_m<p_{mi}$, X_{ede} increases with increase of p_m. Similarly, for $p_m>p_{mi}$, the inequality $[(p_f/p_{fi})\{(1-p_m)(X_f)^{(-1)}+ p_m(X_m)^{(-1)}\}^{(-1)}] > [(p_f/p_{fi})X]$ can be proved.

Appendix 5

COUNTRY	Life Exp. Female (in yrs)	Life Exp. Male (in yrs)	Sex ratio (males/ females)	Conventional Rank	Sex ratio adjusted Rank	Rank Diff.	Gender Prop. Diff.
Iceland	83.1	79.9	1.000	3	1	2	0.000
Japan	85.7	78.7	0.955	1	2	-1	0.023
Australia	83.3	78.5	0.976	5	3	2	0.012
Sweden	82.7	78.3	0.985	7	4	3	0.008
Canada	82.6	77.9	0.983	8	5	3	0.009
Israel	82.3	78.1	0.979	10	6	4	0.011
Spain	83.8	77.2	0.965	6	7	-1	0.018
Norway	82.2	77.3	0.987	12	8	4	0.007
Switzerland	83.7	78.5	0.939	4	9	-5	0.031
Singapore	81.4	77.5	1.014	14	10	4	-0.007
New Zealand	81.8	77.7	0.966	13	11	2	0.017
Netherlands	81.4	76.9	0.986	16	12	4	0.007
France	83.7	76.6	0.949	11	13	-2	0.026
Hong Kong, China (SAR)	84.9	79.1	0.889	2	14	-12	0.059
Italy	83.2	77.2	0.943	9	15	-6	0.029
Malta	81.1	76.8	0.985	17	16	1	0.007
Ireland	80.9	76.0	0.989	26	17	9	0.005
Greece	80.9	76.7	0.977	24	18	6	0.012
Austria	82.2	76.5	0.956	15	19	-4	0.022
Belgium	81.8	75.8	0.963	23	20	3	0.019
Germany	81.8	76.2	0.955	20	21	-1	0.023
Cuba	79.8	75.8	1.002	32	22	10	-0.001
Chile	81.3	75.3	0.979	28	23	5	0.011
Korea (Republic of)	81.5	74.3	1.005	29	24	5	-0.003
United Kingdom	81.2	76.7	0.955	21	25	-4	0.023
Finland	82.0	75.6	0.959	22	26	-4	0.021
Costa Rica	80.9	76.2	1.034	25	27	-2	-0.017
Luxembourg	81.4	75.4	0.970	27	28	-1	0.015
Cyprus	81.5	76.6	0.946	18	29	-11	0.028
Denmark	80.1	75.5	0.980	31	30	1	0.010
United States	80.4	75.2	0.968	30	31	-1	0.016
Slovenia	81.1	73.6	0.953	35	32	3	0.024
Portugal	80.9	74.5	0.935	34	33	1	0.033
Albania	79.5	73.1	0.984	38	34	4	0.008
Belize	79.1	73.1	1.015	39	35	4	-0.007
Brunei Darussalam	79.3	74.6	1.078	36	36	0	-0.037
Panama	77.8	72.7	1.018	46	37	9	-0.009
Barbados	79.3	73.6	0.935	37	38	-1	0.033
Ecuador	77.7	71.8	1.006	50	39	11	-0.003
Czech Republic	79.1	72.7	0.949	40	40	0	0.026
Mexico	78.0	73.1	0.956	44	41	3	0.023
Uruguay	79.4	72.2	0.942	42	42	0	0.030
Macedonia (TFYR)	76.3	71.4	0.996	53	43	10	0.002
Argentina	78.6	71.1	0.957	49	44	5	0.022
Viet Nam	75.7	71.9	0.998	54	45	9	0.001
Poland	79.4	71.0	0.942	48	46	2	0.030
Croatia	78.8	71.8	0.928	45	47	-2	0.037
Syrian Arab Republic	75.5	71.8	1.013	57	48	9	-0.007
Tunisia	75.6	71.5	1.015	58	49	9	-0.008
Venezuela (Bolivarian Republic of)	76.3	70.4	1.010	59	50	9	-0.005
Bosnia and Herzegovina	77.1	71.8	0.945	51	51	0	0.028
Malaysia	76.1	71.4	1.031	55	52	3	-0.015
Slovakia	78.2	70.3	0.942	52	53	-1	0.030
Saint Lucia	75.0	71.3	0.963	60	54	6	0.019
Libyan Arab Jamahiriya	76.3	71.1	1.066	56	55	1	-0.032
Mauritius	75.8	69.1	0.986	68	56	12	0.007
Occupied Palestinian Territories	74.4	71.3	1.035	62	57	5	-0.017
Nicaragua	75.0	69.0	0.999	74	58	16	0.001
Tonga	73.8	71.8	1.040	64	59	5	-0.020
Colombia	76.0	68.7	0.977	69	60	9	0.012
Jamaica	74.9	69.6	0.977	71	61	10	0.012

COUNTRY	Life Exp. Female (in yrs)	Life Exp. Male (in yrs)	Sex ratio (males/ females)	Conventional Rank	Sex ratio adjusted Rank	Rank Diff.	Gender Prop. Diff.
China	74.3	71.0	1.056	65	62	3	-0.027
Bulgaria	76.4	69.2	0.939	63	63	0	0.031
Algeria	73.0	70.4	1.018	79	64	15	-0.009
Dominican Republic	74.8	68.6	1.019	78	65	13	-0.010
Brazil	75.5	68.1	0.972	76	66	10	0.014
Turkey	73.9	69.0	1.016	82	67	15	-0.008
Bahamas	75.0	69.6	0.946	70	68	2	0.028
Paraguay	73.4	69.2	1.015	83	69	14	-0.007
Sri Lanka	75.6	67.9	1.033	77	70	7	-0.016
Romania	75.6	68.4	0.951	73	71	2	0.025
Philippines	73.3	68.9	1.014	86	72	14	-0.007
Saint Vincent and the Grenadines	73.2	69.0	0.983	87	73	14	0.008
Hungary	77.0	68.8	0.909	61	74	-13	0.048
Egypt	73.0	68.5	1.006	90	75	15	-0.003
Lebanon	73.7	69.4	0.961	81	76	5	0.020
Peru	73.3	68.2	1.011	89	77	12	-0.005
El Salvador	74.3	68.2	0.967	84	78	6	0.017
Morocco	72.7	68.3	0.988	93	79	14	0.006
Jordan	73.8	70.3	1.082	72	80	-8	-0.039
Indonesia	71.6	67.8	0.997	96	81	15	0.001
Iran (Islamic Republic of)	71.8	68.7	1.029	94	82	12	-0.014
uriname	73.0	66.4	0.996	97	83	14	0.002
Lithuania	78.0	66.9	0.874	67	84	-17	0.067
Samoa	74.2	67.8	1.079	88	85	3	-0.038
Honduras	73.1	65.8	1.016	99	86	13	-0.008
Oman	76.7	73.6	1.284	47	87	-40	-0.124
Thailand	74.5	65.0	0.965	98	88	10	0.018
Cape Verde	73.8	67.5	0.920	91	89	2	0.041
Saudi Arabia	74.6	70.3	1.172	66	90	-24	-0.079
Trinidad and Tobago	71.2	67.2	0.973	101	91	10	0.014
Guatemala	73.2	66.2	0.950	95	92	3	0.025
Bahrain	77.0	73.9	1.323	43	93	-50	-0.139
Armenia	74.9	68.2	0.873	80	94	-14	0.068
Vanuatu	71.3	67.5	1.038	100	95	5	-0.019
Georgia	74.5	66.7	0.896	92	96	-4	0.055
Latvia	77.3	66.5	0.843	75	97	-22	0.085
Grenada	69.8	66.5	0.981	105	98	7	0.010
Fiji	70.6	66.1	1.034	104	99	5	-0.017
Estonia	76.8	65.5	0.851	85	100	-15	0.080
Kuwait	79.6	75.7	1.500	33	101	-68	-0.200
Uzbekistan	70.0	63.6	0.989	109	102	7	0.005
Moldova	72.0	64.7	0.916	103	103	0	0.044
Tajikistan	69.0	63.8	0.986	110	104	6	0.007
Azerbaijan	70.8	63.5	0.943	107	105	2	0.029
Maldives	67.6	66.6	1.056	108	106	2	-0.027
Belarus	74.9	62.7	0.877	102	107	-5	0.065
Mongolia	69.2	62.8	1.004	111	108	3	-0.002
Kyrgyzstan	69.6	61.7	0.970	113	109	4	0.015
Bolivia	66.9	62.6	0.993	118	110	8	0.003
Sao Tome and Principe	66.7	63.0	0.987	116	111	5	0.006
Ukraine	73.6	62.0	0.847	106	112	-6	0.083
Bhutan	66.5	63.1	1.027	117	113	4	-0.013
Kazakhstan	71.5	60.5	0.920	112	114	-2	0.042
Comoros	66.3	62.0	1.005	120	115	5	-0.003
Guyana	68.1	62.4	0.941	114	116	-2	0.031
Pakistan	64.8	64.3	1.060	119	117	2	-0.029
Lao People’s Democratic Republic	64.5	61.9	1.001	123	118	5	-0.001
Mauritania	65.0	61.5	0.979	122	119	3	0.011
India	65.3	62.3	1.052	121	120	1	-0.026
Russian Federation	72.1	58.6	0.866	115	121	-6	0.072
Bangladesh	64.0	62.3	1.045	124	122	2	-0.022
Turkmenistan	67.0	58.5	0.970	126	123	3	0.015
Nepal	62.9	62.1	0.982	128	124	4	0.009

COUNTRY	Life Exp. Female (in yrs)	Life Exp. Male (in yrs)	Sex ratio (males/ females)	Conventional Rank	Sex ratio adjusted Rank	Rank Diff.	Gender Prop. Diff.
Senegal	64.4	60.4	0.968	127	125	2	0.016
Solomon Islands	63.8	62.2	1.069	125	126	-1	-0.033
Yemen	63.1	60.0	1.029	129	127	2	-0.014
Myanmar	64.2	57.6	0.986	130	128	2	0.007
United Arab Emirates	81.0	76.8	2.137	19	129	-110	-0.363
Haiti	61.3	57.7	0.971	132	130	2	0.015
Ghana	59.5	58.7	1.025	133	131	2	-0.012
Gambia	59.9	57.7	0.983	134	132	2	0.009
Timor-Leste	60.5	58.9	1.081	131	133	-2	-0.039
Qatar	75.8	74.6	2.064	41	134	-93	-0.347
Madagascar	60.1	56.7	0.990	135	135	0	0.005
Togo	59.6	56.0	0.976	137	136	1	0.012
Sudan	58.9	56.0	1.013	138	137	1	-0.007
Cambodia	60.6	55.2	0.935	136	138	-2	0.033
Papua New Guinea	60.1	54.3	1.064	139	139	0	-0.031
Gabon	56.9	55.6	0.991	141	140	1	0.004
Eritrea	59.0	54.0	0.964	140	141	-1	0.018
Benin	56.5	54.1	1.016	143	142	1	-0.008
Niger	54.9	56.7	1.046	142	143	-1	-0.023
Guinea	56.4	53.2	1.051	144	144	0	-0.025
Djibouti	55.2	52.6	0.997	146	145	1	0.001
Congo	55.2	52.8	0.984	145	146	-1	0.008
Mali	55.3	50.8	0.993	147	147	0	0.003
Kenya	53.1	51.1	1.003	148	148	0	-0.001
Ethiopia	53.1	50.5	0.990	149	149	0	0.005
Namibia	52.2	50.9	0.983	150	150	0	0.008
Burkina Faso	52.9	49.8	1.011	151	151	0	-0.005
Tanzania (United Republic of)	52.0	50.0	0.990	152	152	0	0.005
South Africa	52.0	49.5	0.965	153	153	0	0.018
Chad	51.8	49.0	0.979	154	154	0	0.010
Equatorial Guinea	51.6	49.1	0.980	155	155	0	0.010
Cameroon	50.2	49.4	0.990	156	156	0	0.005
Uganda	50.2	49.1	1.001	157	157	0	-0.001
Burundi	49.8	47.1	0.954	158	158	0	0.024
Botswana	48.4	47.6	0.965	159	159	0	0.018
Côte d'Ivoire	48.3	46.5	1.034	160	160	0	-0.017
Nigeria	47.1	46.0	1.024	161	161	0	-0.012
Malawi	46.7	46.0	0.986	162	162	0	0.007
Guinea-Bissau	47.5	44.2	0.976	163	163	0	0.012
Congo (Democratic Republic of the)	47.1	44.4	0.984	164	164	0	0.008
Rwanda	46.7	43.6	0.940	165	165	0	0.031
Central African Republic	45.0	42.3	0.952	166	166	0	0.025
Mozambique	43.6	42.0	0.938	167	167	0	0.032
Sierra Leone	43.4	40.2	0.973	169	168	1	0.014
Angola	43.3	40.1	0.973	170	169	1	0.014
Lesotho	42.9	42.1	0.870	168	170	-2	0.070
Zambia	40.6	40.3	1.003	173	171	2	-0.001
Zimbabwe	40.2	41.4	0.984	172	172	0	0.008
Swaziland	41.4	40.4	0.931	171	173	-2	0.036

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