Annex 2. JRC Statistical Assessment of the 2015 ICT Development Index[1]

Summary

Since 2009, the International Telecommunication Union (ITU) has been publishing its annual ICT Development Index (IDI), which benchmarks countries' performance with regard to ICT infrastructure, use and skills. The JRC analysis, conducted at ITU's invitation, suggests that the conceptualized three-level structure of the 2015 IDI is statistically sound in terms of coherence and balance, with the overall index as well as the three sub-indices – on ICT access, use and skills – being driven by all the underlying components. The IDI has a very high statistical reliability of 0.96 and captures the single latent phenomenon underlying the three main dimensions of the IDI conceptual framework.

Country rankings are also robust with respect to methodological changes in the data normalization method, weighting and aggregation rule (a shift of less than ± 3 positions with respect to the simulated median in 96 per cent of the 167 countries).

The added value of the IDI lies in its ability to summarize different aspects of ICT development in a more efficient and parsimonious manner than is possible with a selection of 11 indicators taken separately. In fact, for between 26 and 52 per cent of the 167 countries included this year, the IDI ranking and any of the three sub-index rankings (access, use and skills) differ by ten positions or more. This is a desired outcome because it evidences the added value of the IDI as a benchmarking tool, inasmuch as it helps to highlight aspects of ICT development that do not emerge directly by looking into ICT access, ICT use and ICT skills separately. At the same time, this result also points to the value of taking due account of the individual ICT dimensions and indicators on their own merit. In so doing, country-specific strengths and bottlenecks in ICT development can be identified and used as an input for evidence-based policy-making.

The IDI is intended for a broad audience of governments, UN agencies, financial institutions and private-sector analysts worldwide. Its aim is to identify strengths and weaknesses in each of the countries under review and encourage policy choices that will advance ICT development. In this respect, assessment of the conceptual and statistical coherence of the IDI and of the impact of modelling choices on a country's performance are fundamental. It adds to the transparency and reliability of the IDI and the building of confidence in the narratives supported by the measure. For this reason, the Econometrics and Applied Statistics Unit of the European Commission's Joint Research Centre (JRC) in Ispra, Italy, was invited by ITU to conduct a thorough statistical assessment of the IDI.[2]

Conceptual and statistical coherence in the IDI

In the seventh (2015) release of its IDI, ITU, a specialized agency of the United Nations, seeks, by means of a selected set of 11 indicators, to summarize complex and versatile concepts underlying ICT development across 167 countries worldwide. This raises practical challenges when it comes to combining these concepts into a single number per country. Indeed, extending what is argued for models in general, stringent transparency criteria must be adopted when composite indicators are used as a basis for policy assessment[3].

The analysis of the conceptual and statistical coherence of the IDI can be synthesized into five main steps:

1. Consideration of the IDI conceptual framework with respect to existing literature.

2. Data-quality checks, including possible reporting errors, missing data, outliers.

3. Assessment of statistical coherence through correlation-based analyses.

4. Assessment of the impact of the weighting scheme and aggregation method.

5. Qualitative confrontation with experts in order to get feedback on the choices made during development of the IDI.

The ITU team has already undertaken the first and last steps, relating for the most part to conceptual issues. The JRC assessment presented below focuses on the second, third and fourth steps, relating to the statistical soundness of the IDI framework and impact of key modelling assumptions on the country rankings. Statistical coherence is pursued by means of three statistical approaches: principal component analysis, reliability item analysis and variance-based analysis. The key modelling assumptions tested include alternative random weights and alternative aggregation formulas (arithmetic and geometric). The JRC analysis complements the IDI country rankings with confidence intervals, in order to better appreciate the robustness of these rankings to the index computation methodology. In addition, the analysis includes an assessment of potential redundancy of information in the IDI framework.

Data checks

The IDI framework builds on three dimensions, or sub-indices, which are aggregated over 11 selected indicators. A complete matrix of 11 indicators, referring to 2014 data for 167 countries, are included in the IDI. These data have been collected annually by ITU through a questionnaire sent to its Member States. Where country data are not available, ITU estimates the missing data using appropriate statistical techniques. The JRC analysis based on the values for skewness and kurtosis[4] suggests that only two indicators – international Internet bandwidth and fixed-broadband subscriptions – have outlier values that could bias the calculation of the aggregate scores and interpretation of the correlation structure. ITU has opted to take the logarithm of international Internet bandwidth and to cap fixed-broadband subscriptions at 60, which is considered to be an ideal value and equal to the maximum value achieved in many developed countries.

The main justification for capping indicators, regardless of whether they are affected by outliers, is the developers' objective to have an ideal value that could be achieved by most countries. For this reason, the ITU team decided to set this ideal value at two standard deviations away from the mean for most indicators.

Instead, the use of logarithmic transformation for international Internet bandwidth goes beyond the need to treat outlier values: it is also aimed at strongly favouring improvements at the lower end of the indicator and at allowing improvements at the higher end to add only a minimal benefit to a country's IDI ranking. The JRC analysis suggests that a further justification for the use of logarithmic transformation is that it increases the correlation of the international Internet bandwidth indicator with the remaining indicators in the ICT access sub-index, whereby the average bivariate correlation of this indicator increases from 0.56 to 0.67 (see Annex Table 2.1).

Principal component analysis and reliability analysis

Principal component analysis (PCA) was used to assess whether the IDI conceptual framework is confirmed by statistical approaches, and to identify possible pitfalls. The expectation is that every aggregate in the IDI framework, whether sub-index or the overall IDI, captures most of the variance in the underlying components. This expectation is confirmed in the IDI framework. In fact, the first principal component captures between 78 per cent (ICT access) and 86 per cent (ICT use) of the total variance in the underlying indicators (Annex Table 2.2). The statistical reliability for each of the IDI sub-indices, measured by the Cronbach-alpha (or c-alpha) coefficient, is very high, at 0.86 (up to 0.91). These values are well above the 0.7 threshold for a reliable aggregate[5]. Particularly important to the reliability of the ICT skills sub-index is the secondary gross enrolment ratio: had this indicator been excluded, the reliability of the ICT skills sub-index would have fallen from 0.86 to 0.71 (see Annex Table 2.2).

Furthermore, the three ICT sub-indices share a single latent dimension that captures 92 per cent of the total variance, and their aggregate, the IDI, has a very high statistical reliability of 0.95. Finally, results confirm the expectation that the indicators

Annex Table 2.1: Impact of log transform of the international Internet bandwidth indicator

	Without log	With log
Fixed-telephone subscriptions per 100 inhabitants	0.68	0.65
Mobile-cellular telephone subscriptions per 100 inhabitants	0.29	0.54
Percentage of households with a computer	0.63	0.76
Percentage of households with Internet access at home	0.63	0.74
Average bivariate correlation	*0.56*	*0.67*

Note: Numbers represent the Pearson correlation coefficient (excluding outliers) between the *international Internet bandwidth per Internet user* indicator (with/without log transformation) and any of the four indicators in the ICT access dimension.
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

Annex Table 2.2: Statistical coherence in the 2015 IDI – Principal components analysis and reliability analysis

ICT Development Index (& sub-indices)	Variance explained	c-alpha	c-alpha when excluding one component				
			#1	#2	#3	#4	#5
ICT Development Index (3 sub-indices)	91.7	0.95	0.89	0.92	0.97		
ICT access sub-index (5 indicators)	78.2	0.91	0.89	0.92	0.91	0.86	0.86
ICT use sub-index (3 indicators)	85.9	0.90	0.79	0.88	0.91		
ICT skills sub-index (3 indicators)	81.0	0.86	0.71	0.85	0.83		

Note: “Variance explained” shows the amount of total variance explained by the first principal component across the three ICT sub-indices, or the indicators in the case of the ICT sub-indices. c-alpha (or Cronbach-alpha) is a measure of statistical reliability (values greater than 0.7 are recommended for good reliability).
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

are more correlated to their own ICT dimension than to any other and that all coefficients are greater than 0.75 (see Annex Table 2.3). This outcome suggests that the indicators have been allocated to the most relevant ICT dimension.

Thus far, the results show that the grouping of the eleven indicators into three ICT sub-indices and to an overall index is statistically coherent at each aggregation level.

Weights and importance

The statistical analysis in the previous sections was based on classical correlation coefficients. In this audit, the assessment is extended to a non-linear context, to anticipate potentially legitimate criticism about the nonlinearity of the associations between the IDI components. To this end, global sensitivity analysis has been employed in order to evaluate an indicator’s contribution to the variance of the IDI dimensions and overall index scores.

The overarching consideration on the part of the ITU team was that the ICT sub-indices on access and use should have equal importance in the IDI and twice as much importance as the sub-index on ICT skills. The lower weight assigned to ICT skills is justified by the developers on the grounds that it is based on proxy variables. Hence, ICT access and ICT use are given weights of 0.4 each, and ICT skills a weight of 0.2. At the same time, within each ICT sub-index, all underlying indicators are given equal weights and considered to be of similar importance.

The tests reported on in this assessment focused on identifying whether the IDI 2015 is statistically well-balanced in its sub-indices, and in its indicators within each sub-index. There are several approaches for such testing, such as eliminating one indicator at a time and comparing the resulting ranking with the original ranking, or using a simple (e.g. Pearson or Spearman rank) correlation coefficient. A more appropriate measure, aptly named ‘main effect’ (henceforth S_i), also known as correlation ratio or first order sensitivity measure[6], has been applied here. The suitability of Pearson’s correlation ratio as a measure of the importance of variables in an index is argued to be fourfold, inasmuch as (a) it offers

Annex Table 2.3: Statistical coherence in the 2015 IDI – Cross-correlations

Indicators	ICT access	ICT use	ICT skills
Fixed-telephone subscriptions per 100 inhabitants	0.877	0.819	0.765
Mobile-cellular telephone subscriptions per 100 inhabitants	0.722	0.607	0.608
International Internet bandwidth per Internet user (log)	0.865	0.789	0.758
Percentage of households with a computer	0.964	0.935	0.828
Percentage of households with Internet access at home	0.962	0.946	0.814
Percentage of individuals using the Internet	0.940	0.955	0.843
Fixed-broadband subscriptions per 100 inhabitants	0.885	0.904	0.775
Mobile-broadband subscriptions per 100 inhabitants	0.802	0.917	0.696
Secondary gross enrolment ratio	0.828	0.766	0.928
Tertiary gross enrolment ratio	0.771	0.778	0.899
Adult literacy rate	0.694	0.663	0.862

Note: Numbers are the classical Pearson correlation coefficients (n=167).
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

a precise definition of importance that is 'the expected reduction in variance of the composite indicator that would be obtained if a variable could be fixed'; (b) it can be used regardless of the degree of correlation between variables; (c) it is model free, in that it can be applied also in non-linear aggregations; and (d) it is not invasive, in that no changes are made to the composite indicator or to the correlation structure of the indicators (as is the case when eliminating one indicator at a time).[7]

The results of this analysis appear in Annex Table 2.4. Examining the S_i's for the three ICT dimensions, we see that the IDI is perfectly balanced with respect to ICT access and ICT use (S_i = 0.96), while ICT skills is slightly less important (0.83). This suggests that the weighting scheme chosen by the development team has indeed led to the desired outcome whereby the two key ICT sub-indices – access and use – are of equal importance, and are more important than ICT skills.

At the sub-index level, the results are similarly reassuring: all indicators are important in classifying countries within each dimension, although some indicators are slightly more important than others. Within the ICT access sub-index, all five indicators are important, with S_i values greater than 0.5. However, the S_i for mobile-cellular telephone subscriptions is significantly smaller than that of the other indicators (0.54 as against 0.75-0.93), despite their equal weights within the ICT access.

The S_i values for households with a computer and households with Internet access at home are very high (0.93), suggesting a relative dominance of those two indicators in the variation of the ICT access scores. This can be explained by the undesirably high correlation (0.98) between these two indicators, which has persisted over the last five years, with a similar correlation having been found in 2010, 2012 and 2013. On statistical grounds, these indicators would need to be assigned half the weight of the other indicators in order to reduce their undue impact on the variation of ICT access scores and on the overall IDI. However, owing to the changing pattern of ICT household access (use of smartphones to access the Internet) and increase in the number of countries collecting the data from official surveys, it is possible that such a correlation may cease to exist over the coming years. The JRC recommendation for next year's release of the IDI is to reassess/revisit the weights assigned to these two indicators.

Within the ICT use sub-index, all three indicators are important, as reflected in their equal weights, although the indicator on individuals using the Internet is slightly more important than the other two, on fixed-broadband subscriptions and mobile-broadband subscriptions (0.91 as against 0.82-0.84). Similarly, within the ICT skills sub-index, all three indicators are important, with the

Annex Table 2.4: Importance measures (variance-based) for the IDI components

IDI sub-index	Importance (S_i) within the IDI	Weights
ICT access	0.96	0.40
ICT use	0.96	0.40
ICT skills	0.83	0.20
IDI indicators	**Importance (*Si*) within an IDI sub-index**	**Weights**
Fixed-telephone subscriptions per 100 inhabitants	0.78	0.20
Mobile-cellular telephone subscriptions per 100 inhabitants	0.54 (*)	0.20
International Internet bandwidth per Internet user (log)	0.76	0.20
Percentage of households with a computer	0.93 (*)	0.20
Percentage of households with Internet access at home	0.93 (*)	0.20
Percentage of individuals using the Internet	0.91	0.33
Fixed-broadband subscriptions per 100 inhabitants	0.82	0.33
Active mobile-broadband subscriptions per 100 inhabitants	0.84	0.33
Secondary gross enrolment ratio	0.86	0.33
Tertiary gross enrolment ratio	0.81	0.33
Adult literacy rate	0.75	0.33

Note: Numbers represent the kernel estimates of the Pearson correlation ratio, as in Paruolo et al., 2013. (*) Sub-factors that make a much lower/higher contribution to the variance of the relevant dimension scores than the equal weighting expectation are marked with an asterisk.
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

adult literacy rate being slightly less important than the other two indicators, relating to the secondary and tertiary gross enrolment ratio (0.75 as against 0.81-0.86).

In short, the weights assigned by the developers to the IDI components coincide, in most cases, with the importance of the IDI components.

Added value of the IDI vis-à-vis the three ICT dimensions

A very high statistical reliability may be the result of redundancy of information in an index. The analysis discussed below reveals that this is not the case in the 2015 IDI. Instead, the high statistical reliability (c-alpha = 0.95) of the IDI is a sign of a statistically sound composite indicator that brings in additional information on the monitoring of ICT development in countries around the world. This is shown in Annex Table 2.5, which presents, for all pairwise comparisons between the IDI and the three sub-indices, the Spearman rank correlation coefficients (above the diagonal) and the percentage of countries that shift ten positions or more (below the diagonal). In fact, for between 26 and 52 per cent of the 167 countries included this year, the IDI ranking and any of the three sub-index rankings – on access, use and skills – differ by ten positions or more. This is a desired outcome because it evidences the added value of the IDI as a benchmarking tool, inasmuch as it helps to highlight aspects of ICT development that do not emerge directly by looking into ICT access, ICT use and ICT skills separately. At the same time, this result also points to the value of taking due account of the individual ICT dimensions and indicators on their own merit. In so doing, country-specific strengths and bottlenecks in ICT development can be identified and used as an input for evidence-based policy-making.

Impact of modelling assumptions on the IDI ranking

The IDI and its underlying sub-indices are the outcome of choices with respect to, among other things: the framework (driven by theoretical models and expert opinion), the indicators included, the normalization of the indicators, the weights assigned to the indicators and to the sub-indices, and the aggregation method. Some of these choices are based on expert opinion or on common practice, driven by statistical

Annex Table 2.5: Added value of the IDI vis-à-vis its main components

	IDI	ICT access	ICT use	ICT skills
IDI	-	0.984	0.984	0.903
ICT access	26%	-	0.953	0.857
ICT use	26%	50%	-	0.860
ICT skills	52%	62%	69%	-

Note: Numbers above the diagonal: Spearman rank correlation coefficients; numbers below the diagonal: percentage of countries (out of 167) that shift +10 positions or more between the rankings.
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

analysis or the need for ease of communication. The aim of the uncertainty analysis is to assess the extent to which – and for which countries in particular – these choices might affect country classification. We have dealt with these uncertainties simultaneously in order to assess their joint influence and fully acknowledge their implications[8]. The data are considered to be error-free since the ITU team already undertook a double-check control of possible errors and corrected them during this phase.

The robustness assessment of the IDI was based on a combination of a Monte Carlo experiment and a multi-modelling approach. This type of assessment aims to respond to any criticism that the country scores associated with aggregate measures are generally not calculated under conditions of certainty, even though they are frequently presented as such[9]. The Monte Carlo simulation was played on the weights for the three sub-indices and comprised 1 000 runs, each corresponding to a different set of weights, randomly sampled from uniform continuous distributions in the range 15-25 per cent for the ICT skills sub-index, and 30-50 per cent for the ICT access and ICT use sub-indices. The sampled weights were then rescaled to unity sum (Annex Table 2.6). This choice of the range for the weights variation ensures a wide enough interval to have meaningful robustness checks (±25 per cent of the reference value and a roughly three-to-one ratio of the highest to the lowest weight). At the same time, it reflects the ITU team's rationale that the ICT skills sub-index should be given less weight than the ICT access and ICT use sub-indices.

The next type of uncertainty considered relates to use of the arithmetic average in the calculation of the index from the three ICT dimensions, a formula that received statistical support from principal component analysis and reliability item analysis. However, decision-theory practitioners have challenged the use of simple arithmetic averages because of their fully compensatory nature, in which a comparative high advantage on a few indicators can compensate a comparative disadvantage on many indicators[10]. In order to account for this criticism, the geometric average was considered as an alternative. The geometric average is a partially compensatory approach that rewards countries with similar performance in the three ICT dimensions or motivates countries to improve in those ICT dimensions in which they perform poorly, and not just in *any* ICT dimension[11].

Combined with the 1 000 simulations per model to account for the uncertainty in the weights across

Annex Table 2.6: Uncertainty parameters (weights and aggregation function)

	Reference	Alternative
I. Uncertainty in the aggregation function at the sub-index level	Arithmetic average	Geometric average
II. Uncertainty intervals for the three sub-index weights	Reference value for the weight	Distribution for uncertainty analysis
ICT access	0.4	U[0.30, 0.50]
ICT use	0.4	U[0.30, 0.50]
ICT skills	0.2	U[0.15, 0.25]

Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

the sub-indices, we conducted a total of 2 000 simulations.

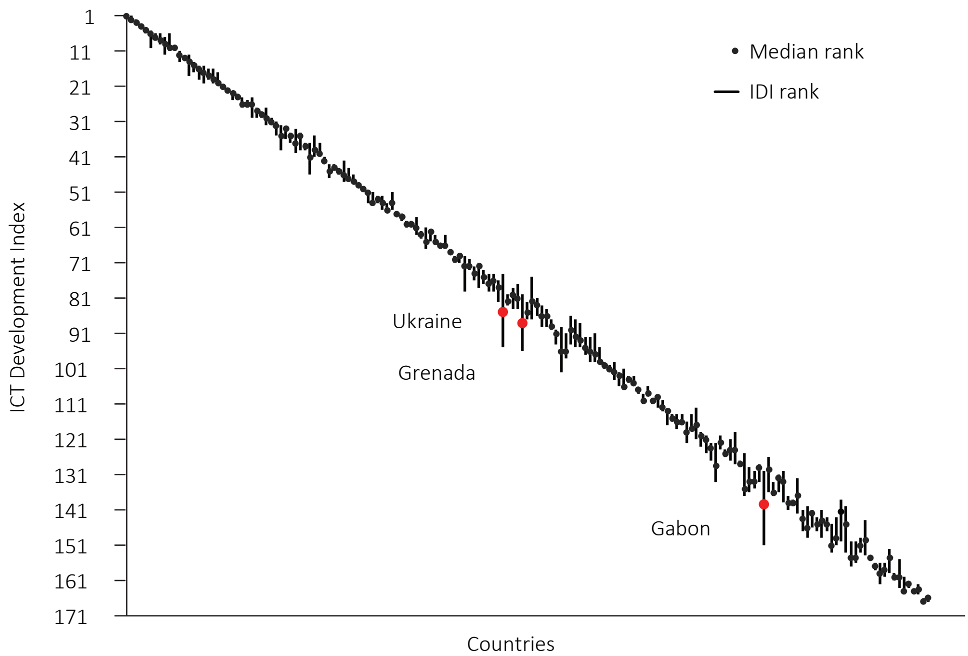
The results of the uncertainty analysis for the IDI are provided in Annex Figure 2.1, which shows median ranks and 90 per cent intervals computed across the 2 000 Monte Carlo simulations. Countries are ordered from the highest to the lowest levels of ICT development according to their reference rank in the IDI (black line), the dot being the simulated median rank. Error bars represent, for each country, the 90 per cent interval across all simulations.

Taking the simulated median rank as being representative of the simulations, then the fact that the IDI ranks are close to the median ranks suggests that the IDI ranking is a suitable summary measure of ICT development. Country ranks in the IDI are very close to the median rank: 90 per cent of the countries shift by less than ± 3 positions with respect to the simulated median. For the vast majority of countries, these modest shifts can be taken as an indication that country classification based on IDI depends mainly on the indicators used and not on the methodological judgments made during the weighting and aggregation phases.

Simulated intervals for most countries are narrow enough, hence robust to changes in the weights and aggregation formula – less than six positions in 75 per cent of the cases for the overall IDI. These results suggest that for the vast majority of the countries, the IDI ranks allow for meaningful inferences to be drawn.

Nevertheless, three countries have relatively wide intervals (more than 15 positions): Ukraine and Gabon (21 positions) and Grenada (16 positions). These relatively wide intervals are due to the compensation effect among the ICT sub-indices, which is evidenced by the use of the geometric average. These cases have been flagged herein as part of the uncertainty analysis, in order to bring more transparency to the entire process and to help appreciate the IDI results with respect to the choices made during the development phase. To this end, Annex Table 2.7 reports the index ranks together with the simulated intervals (90 per cent of the 2 000 scenarios simulating uncertainties in the weights and the aggregation formula for the three ICT dimensions).

Annex Figure 2.1: Uncertainty analysis of the IDI (ranks vs median rank, 90 per cent intervals)



Note: Countries are ordered from high to low levels of ICT development. Median ranks and intervals are calculated over 2 000 simulated scenarios combining random weights for the three ICT dimensions (25 per cent above/below the reference value), and geometric versus arithmetic average at the dimension level. Countries with wide intervals (more than 15 positions) are flagged.
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

Annex Table 2.7: IDI country ranks and 90 per cent intervals

Countries	IDI rank	90% interval
Afghanistan	156	[156, 158]
Albania	94	[87, 95]
Algeria	113	[113, 117]
Andorra	28	[27, 30]
Angola	140	[132, 142]
Antigua & Barbuda	62	[62, 64]
Argentina	52	[51, 55]
Armenia	76	[74, 79]
Australia	13	[13, 13]
Austria	25	[24, 27]
Azerbaijan	67	[63, 67]
Bahrain	27	[24, 30]
Bangladesh	144	[143, 147]
Barbados	29	[28, 30]
Belarus	36	[33, 40]
Belgium	21	[21, 21]
Belize	116	[114, 117]
Benin	151	[150, 157]
Bhutan	119	[112, 121]
Bolivia	107	[107, 108]
Bosnia and Herzegovina	77	[74, 79]
Botswana	111	[109, 112]
Brazil	61	[58, 63]
Brunei Darussalam	71	[69, 79]
Bulgaria	50	[50, 50]
Burkina Faso	159	[152, 159]
Cambodia	130	[129, 136]
Cameroon	147	[145, 153]
Canada	23	[23, 25]
Cape Verde	96	[92, 97]
Chad	167	[166, 167]
Chile	55	[54, 56]
China	82	[77, 84]
Colombia	75	[73, 77]
Congo (Dem. Rep.)	160	[159, 161]
Congo (Rep.)	141	[141, 147]
Costa Rica	57	[57, 58]
Côte d'Ivoire	137	[130, 139]
Croatia	42	[41, 42]
Cuba	129	[125, 137]
Cyprus	53	[52, 54]
Czech Republic	34	[33, 36]
Denmark	2	[1, 3]
Djibouti	148	[143, 151]
Dominica	80	[80, 83]
Dominican Rep.	103	[102, 106]
Ecuador	90	[90, 94]
Egypt	100	[99, 101]
El Salvador	106	[103, 106]
Equatorial Guinea	146	[143, 147]
Eritrea	166	[166, 167]
Estonia	20	[17, 20]
Ethiopia	165	[162, 165]
Fiji	101	[100, 101]
Finland	12	[11, 14]
France	17	[15, 20]
Gabon	133	[130, 151]
Gambia	135	[133, 137]
Georgia	78	[76, 82]
Germany	14	[12, 18]
Ghana	109	[106, 109]
Greece	39	[37, 46]
Grenada	83	[80, 96]
Guatemala	121	[120, 125]
Guinea-Bissau	162	[160, 165]
Guyana	114	[114, 116]
Honduras	120	[119, 123]
Hong Kong, China	9	[7, 12]
Hungary	48	[46, 48]
Iceland	3	[2, 3]
India	131	[130, 135]
Indonesia	108	[108, 111]
Iran (I.R.)	91	[89, 102]
Ireland	22	[22, 22]
Israel	35	[34, 37]
Italy	38	[37, 39]
Jamaica	105	[103, 105]
Japan	11	[10, 11]
Jordan	92	[91, 98]
Kazakhstan	58	[57, 59]
Kenya	124	[120, 124]
Korea (Rep.)	1	[1, 2]
Kuwait	46	[42, 48]
Kyrgyzstan	97	[92, 99]

Countries	IDI rank	90% interval
Lao P.D.R.	138	[137, 141]
Latvia	37	[34, 39]
Lebanon	56	[51, 56]
Lesotho	128	[127, 129]
Liberia	155	[154, 155]
Lithuania	40	[35, 41]
Luxembourg	6	[5, 10]
Macao, China	24	[23, 25]
Madagascar	164	[164, 164]
Malawi	163	[162, 163]
Malaysia	64	[62, 65]
Maldives	81	[78, 84]
Mali	145	[141, 149]
Malta	30	[27, 32]
Mauritania	150	[140, 153]
Mauritius	73	[72, 76]
Mexico	95	[88, 95]
Moldova	66	[66, 67]
Monaco	18	[16, 19]
Mongolia	84	[82, 87]
Montenegro	65	[63, 66]
Morocco	99	[95, 99]
Mozambique	158	[156, 160]
Myanmar	142	[140, 149]
Namibia	118	[114, 118]
Nepal	136	[131, 136]
Netherlands	8	[6, 9]
New Zealand	16	[15, 19]
Nicaragua	123	[122, 133]
Nigeria	134	[126, 136]
Norway	10	[6, 11]
Oman	54	[52, 56]
Pakistan	143	[141, 146]
Panama	89	[87, 90]
Paraguay	112	[110, 113]
Peru	104	[101, 107]
Philippines	98	[91, 99]
Poland	44	[43, 45]
Portugal	43	[43, 47]
Qatar	31	[30, 31]
Romania	59	[59, 61]
Russian Federation	45	[44, 46]
Rwanda	154	[144, 154]
Samoa	122	[122, 127]
Saudi Arabia	41	[37, 41]
Senegal	132	[128, 133]
Serbia	51	[51, 54]
Seychelles	87	[83, 89]
Singapore	19	[16, 20]
Slovakia	47	[44, 48]
Slovenia	33	[32, 39]
Solomon Islands	139	[138, 140]
South Africa	88	[84, 89]
South Sudan	161	[155, 163]
Spain	26	[25, 27]
Sri Lanka	115	[114, 118]
St. Kitts and Nevis	63	[61, 67]
St. Lucia	86	[81, 86]
St. Vincent and the Grenadines	68	[68, 68]
Sudan	126	[121, 127]
Suriname	85	[75, 87]
Sweden	5	[5, 6]
Switzerland	7	[6, 8]
Syria	117	[116, 122]
Tanzania	157	[156, 162]
TFYR Macedonia	60	[59, 61]
Thailand	74	[71, 78]
Togo	152	[150, 156]
Tonga	110	[110, 111]
Trinidad & Tobago	70	[69, 71]
Tunisia	93	[86, 94]
Turkey	69	[69, 71]
Uganda	149	[138, 150]
Ukraine	79	[74, 95]
United Arab Emirates	32	[31, 35]
United Kingdom	4	[4, 4]
United States	15	[14, 17]
Uruguay	49	[49, 49]
Vanuatu	125	[124, 126]
Venezuela	72	[70, 73]
Viet Nam	102	[99, 104]
Zambia	153	[149, 153]
Zimbabwe	127	[119, 128]

Note: Countries are presented in alphabetical order. 90 per cent intervals are calculated over 2 000 simulated scenarios combining random weights for the three ICT dimensions (25 per cent above/below the reference value), and geometric versus arithmetic average at the dimension level.
Source: Saisana and Domínguez-Torreiro, European Commission, Joint Research Centre; IDI 2015.

The choice of aggregation function at the sub-index level is the main driver of the variation in country ranks. Following best practices in the relevant literature and choosing the average absolute shift in rank as our robustness metric[12], we found that the aggregation function choice accounts for 95 per cent of the sample variance, while the dimensions' weights choice accounts for only 5 per cent. This result suggests that, should the methodological choices behind IDI 2015 stimulate further discussion, then this should focus more on the aggregation formula for the three ICT dimensions and much less on their weights.

As a general remark, the robustness of an index should not be interpreted as an indication of the index quality. It is instead a consequence of the index dimensionality. In other words, robustness is to some extent the flip side of redundancy: a very high correlation between variables will lead to an index ranking that is practically unaffected by the methodological choices, so the index will be both robust and redundant. Similarly, a low correlation among variables would imply that the methodological choices are very important in determining country rankings, and thus the index is unlikely to be robust to those choices.

The results herein have revealed that country classification based on the IDI depends mainly on the indicators used and not on the methodological judgments made, thus allowing for meaningful inferences to be drawn. In fact, 90 per cent of the countries shift by less than ± 3 positions with respect to the simulated median. At the same time, the IDI ranking has been found to have an added value as a benchmarking tool, highlighting aspects of ICT development that do not emerge directly by looking at the three underlying sub-indices. For between 26 and 52 per cent of the 167 countries included this year, the IDI ranking and any of the three sub-index rankings (access, use and skills) differ by ten positions or more. Consequently, the IDI 2015 is robust without being redundant.

Conclusions

ITU invited JRC to delve into the statistical properties of the 2015 IDI in order to assess the transparency and reliability of the results and enable academics and policy-makers to derive more accurate and meaningful conclusions. ITU's objective was to ensure that the IDI conforms to stringent transparency and replicability criteria and that the statistical priorities used in the IDI make it a credible and legitimate tool for improved policy-making.

The JRC analysis suggests that the conceptualized three-level structure of ITU's *2015 IDI* – calculated through 11 indicators related to ICT access, use and skills for 167 countries – is statistically sound, coherent and balanced. Indeed, within each ICT dimension a single latent factor is identified and all indicators are important in determining the variation of the respective dimension scores.

Country rankings in the overall IDI are also fairly robust to methodological changes in the data normalization method, weighting and aggregation rule (a shift of less than ± 3 positions in 96 per cent of the cases). Consequently, benchmarking inferences can be drawn for most countries in the IDI, while some caution may be needed for three countries. It is to be noted that perfect robustness would have been undesirable as this would have implied that the IDI components are perfectly correlated and hence redundant, which is not the case. In fact, one way in which the IDI 2015 helps to highlight other aspects of ICT development is by pinpointing the differences in rankings that emerge from a comparison between the IDI and each of the three dimensions, namely ICT access, ICT use and ICT skills. For between 26 and 52 per cent of the countries, the IDI ranking and any of the three sub-index rankings differ by ten positions or more.

The main refinement suggested by the present analysis relates to the highly correlated indicators within the ICT access sub-index – percentage of households with a computer and percentage of households with Internet access at home. On statistical grounds, these indicators would need to be assigned half the weight of the other indicators in order to reduce their undue impact on the variation of ICT access scores and on the overall IDI. However, owing to the changing pattern of ICT household access (use of smartphones to access the Internet) and the increase in the number of countries collecting the data from official surveys, it is possible that such correlation will cease to exist over the coming years. Accordingly, the methodology used for these indicators should be revisited/reassessed in future releases of the IDI.

The added value of IDI 2015 – developed using international quality standards and tested using state-of-the-art statistical analyses – lies in its ability to summarize different aspects of ICT development in a more efficient and parsimonious manner than is possible with a selection of 11 indicators taken separately. In fact, the IDI has a very high reliability of 0.95 and indeed captures the single latent phenomenon underlying the ICT access, ICT use and ICT skills sub-indices. In past reports, ITU did not include a detailed discussion of the statistical properties of the IDI. It is to be hoped that this year's initiative to provide a detailed statistical assessment of the IDI will reinforce media uptake of the IDI and ITU's engagement with civil society.

Endnotes

[1] This was prepared by Michaela Saisana and Marcos Dominguez-Torreiro, from European Commission, Joint Research Centre (JRC), Econometrics and Applied Statistics Unit, based in Italy.

[2] The JRC analysis was based on the recommendations of the OECD/EC JRC (2008) Handbook on Composite Indicators, and on more recent academic research from JRC. The JRC auditing studies of composite indicators are available at https://ec.europa.eu/jrc/en/coin.

[3] Saltelli and Funtowisz (2014).

[4] Skewness greater than 2 and kurtosis greater than 3.5; Groeneveld and Meeden (1984) set the criteria for absolute skewness above 1 and kurtosis above 3.5. The skewness criterion was relaxed to 'above 2' to account for the small sample (167 countries).

[5] Nunnally (1978).

[6] Saltelli *et al.* (2008).

[7] Paruolo *et al.* (2013).

[8] Saisana *et al.* (2005).

[9] Saisana *et al.* (2011).

[10] Munda (2008).

[11] In the geometric average, indicators are multiplied as opposed to summed in the arithmetic average. Indicator weights appear as exponents in the multiplication.

[12] Saisana *et al.* (2005).