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MEASURING THE ICT DEVELOPMENT: THE FUSION OF BIASED AND OBJECTIVE APPROACH

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Abstract: *Majority of studies support the viewpoint that Information and Communication Technologies (ICT) have a positive effect on the level of economic activity and the overall societal development. Accordingly, on the global level, the penetration of ICT in countries and regions is growing each day. Thus, measuring country's ICT development is an issue that attracts the attention of various stakeholders. One of the metrics developed to monitor and compare the level of ICT development between countries is the ICT Development Index (IDI). Several conducted studies put an accent on IDI's disadvantages, the main being its bias, and a major study was recently published that bypasses the bias and introduces the objectiveness to the measurement method of the IDI. Therefore, it suggests the Composite I-distance Indicator (CIDI) methodology to overcome the drawback of subjectivity within a composite indicator. However, it raised certain concerns regarding the possibility of excessive objectiveness that may not be in accordance with the nature of IDI measurement. Having in mind that the IDI comprises of pillars, which are comprised of indicators, the question arises whether weights on both indicator levels should be unbiased. Although CIDI could be applied on both levels, we propose a slightly different approach, the hybrid approach that incorporates both bias and objectiveness into the IDI methodology. Namely, our idea is that the indicator weights would be objective while the pillar weights would be left intact. The results of this paper might indicate that when scrutinizing composite indicators weighting schemes, researchers need not alter weights on all indicator levels. Better results could be obtained by mixing the appropriate amount of bias from experts and objectiveness from data itself. Our hybrid approach could be a foundation for further research that would take into account both approaches to assigning weights: the biased and the unbiased approach.*
Keywords: *CIDI methodology, Composite indicators, Information and Communication Technologies (ICT), Information Development Index (IDI)*

INTRODUCTION

It has been widely accepted and elaborated that Information and Communication Technologies (ICT) have an impact on opening economic opportunities, on promoting social and political changes, on the evolution of the learning process and on the access to the shared best practice [1]. However, differences in the implementation level of ICT among countries worldwide are staggering [2]. Therefore, it is no wonder the world is beginning to divide by technology, not by ideology [3].
Since the second half of the 20th century, informational scientists have been trying to include the ICT into policy agenda for its benefits. To achieve such a task they needed a measure of national ICT access, usage, skills and infrastructure. Since their initiative on creating an ICT measurement, such metrics have proliferated. However, most authors are not satisfied with the overall achievements and stress out limitations of their colleagues' work. For example, Richard Taylor [4] in his paper calls for a "grand challenge" in the field of ICT measurements, remarking eight key issues that should be addressed. One on them is of particular interest for this study: the issue of the measurement methodology. The general impression is that alternative approaches are needed to improve the currently used indicators and composite indices. Nevertheless, international institutions and policy makers acknowledged the possible benefits of ICT metrics. A proof for that is the fact that the World Economic Forum overtook the Network Readiness Index (NRI) from the Harvard University in 2002.
Besides the NRI, ICT Development Index (IDI) is one of the most widely used and recognized indices for measuring the level of ICT. The United Nations International Telecommunication Union devised this composite index in 2009. Consisted of 11 indicators and three pillars, IDI aims at measuring, monitoring and comparing developments in Information and Communication Technology across countries [5]. One of its main drawbacks is that it measures only the technological and social aspect of ICT development, leaving behind its implications on the economy, government and education [1]. Another limitation of IDI, important for this research, is its biased weighting scheme [6].
The aim of weights in a composite indicator (CI) is to reflect the relative importance of each of the indicators and/or categories. Namely, when creating a CI, there are many different weighting techniques that can be applied [7,8]. Some of them are completely based on expert opinion (subjective methods) while others completely rely on the provided data (objective methods) [9]. Neither group of weighting methods is above criticism. Namely, objective methods tend to restrict the index creators in the process of assigning weights, as they do not allow them to include expert opinion [10]. On the other hand, a more recent study

showed expert opinion should be taken into account when devising a CI [11]. Subjective methods have the ability to represent the expert and public preferences, which is of high importance for policy makers. However, subjectivity is always questionable, especially in such an important step in creating a composite indicator [12]. Therefore, applying one weighting methodology might result in the rigidity of the measurement.

To overcome the issue, we attempted to create a hybrid weighting approach. We modified the already elaborated twofold I-distance approach [13] for scrutinizing composite indicators. Namely, we propose a fusion of biased and objective approach which undermines applying a statistical Composite I-distance Indicator (CIDI) methodology to create data-derived weights on one level of composite indicator, while the weights on the other level will be left as provided by experts. CIDI methodology has been employed as it has been used with great success to obtain unbiased weighting schemes [6,14]. Applying the proposed approach has two benefits: First, the expert opinion will be included in the indicator methodology, and second, the level of bias will be significantly reduced.

When creating a hybrid approach, another question arises: which indicator level should be subjective and which should be objective. Our idea was to leave the weights of pillars into the overall result as recommended by the experts while to create new weights of indicators within pillars. This methodology, although hybrid, largely reduces the level of subjectivity of the CI. Figure 1 provides a graphic interpretation of our suggested approach.

Figure 1 The hybrid approach for scrutinizing composite indicators

To test our newly devised approach, we chose to employ it on the IDI for several reasons. Firstly, the IDI weighting scheme is subjective on both levels and secondly, because recently a major study was conducted to introduce objectiveness into the measurement of the IDI. Therefore, we elected IDI to continue the study on its biased weighting scheme.

The paper is organized as follows: the second section features the IDI methodology, followed by the statistical methods used to perform the analysis. The results are given in Section IV, while the results of the uncertainty and sensitivity analysis, used to evaluate the obtained weights shall be elaborated in Section V. The concluding remarks are provided in the final chapter.

ICT DEVELOPMENT INDEX (IDI)

ICT Development Index (IDI) is a benchmarking tool used to monitor information society development worldwide [6]. Through three pillars, it aims to measure the evolution of ICT over time in both developed and developing countries. Besides, two other of its objectives are to measure the digital divide between countries and the extent to which countries make use of their ICT infrastructure.

IDI is divided into the following three pillars:

- *ICT Access* reflects the level of network infrastructure and access to ICTs, capturing its readiness. This pillar is measured through 5 indicators.
- *ICT Use* reflects the level of use of ICTs in a society, capturing its intensity using 3 indicators.
- *ICT Skills* reflects the result/outcome of efficient and effective ICT use, capturing its capability or skills through 3 indicators.

Although the development of such a comprehensive methodology such as IDI is a major step towards measuring the ICT development and divide, it still has place for alterations. One of its limitations is that it only ranks countries and does not provide regional data [15] which might be useful. Another drawback of IDI and its methodology is the weighting scheme. The detailed list of indicators within each pillar and their respective weights are given in Table 1:

Table 1 ICT Development Index: indicators and weights

ICT Access	**(a) Pillar weight**	**(b) Indicator weight**	**Overall weight (a*b)**
1. Fixed-telephone subscriptions per 100 inhabitants		20%	8%
2. Mobile-cellular telephone subscriptions per 100 inhabitants		20%	8%
3. International Internet bandwidth (bit/s) per Internet user	40%	20%	8%
4. Percentage of households with a computer		20%	8%
5. Percentage of households with Internet access		20%	8%
ICT Use	**(a) Pillar weight**	**(b) Indicator weight**	**Overall weight (a*b)**
6. Percentage of individuals using the Internet		33%	13.3%
7. Fixed (wired)-broadband subscriptions per 100 inhabitants	40%	33%	13.3%
8. Wireless-broadband subscriptions per 100 inhabitants		33%	13.3%
ICT Skills	**(a) Pillar weight**	**(b) Indicator weight**	**Overall weight (a*b)**
9. Adult literacy rate		33%	6.7%
10. Secondary gross enrolment ratio	20%	33%	6.7%
11. Tertiary gross enrolment ratio		33%	6.7%

Since the weights shown in Table 1 are comprehensively biased [16], and since the CIDI approach made this measure of information development completely objective [6,14] the issue at hand was to create a specific CI that would combine biased and objective approach in the specific amount. Such approach would make the CI the best possible measurement that has the benefits of both weighting approaches. Thus, we decided to keep the pillar weights as proposed by experts, but instead of giving equal weights to each of the compounding indicators, we calculated the objective weights for them. In this way, the CI obtained is a right mix of biased and objective, taking into account the opinion of experts, but still does not allow experts the complete freedom in choosing the weights.

STATISTICAL METHODOLOGIES

A need for a statistical methodology that will be able to rank entities based on a number of indicators of different measurements appeared in 1970’s. A method devised and named by Ivanovic [17], the I-distance method, was able to answer such a task. This method is based on calculating the mutual distances between the entities being processed, whereupon they are compared to one another so as to create a rank [18]. To rank entities (in this case countries) by using the I-distance method, it is necessary to determine one entity as a referent in the observed set. The referent entity can be the minimal, maximal or average observed or fictive value [19]. In our analysis, the referent entity was the one with the minimal values.

For a selected set of variables $X^T = (X_1, X_2, ...X_k)$ chosen to characterize the entities, the I-distance between the two entities $e_r = (x_{1r}, x_{2r}, ...x_{kr})$ and $e_s = (x_{1s}, x_{2s}, ...x_{ks})$ is defined as:

$$D(r,s) = \sum_{i=1}^{k} \frac{|d_i(r,s)|}{\sigma_i} \prod_{j=1}^{i-1} \left(1 - r_{ji.12...j-1}\right)$$

(1)

where $d_i(r,s)$ is the distance between the values of variable X_i for e_r and e_s e.g. the discriminate effect

$$d_i(r,s) = x_{ir} - x_{is} \quad i \in \{1,...k\}$$

(2)

σ_i is the standard deviation of X_i, and $r_{ji.12...j-1}$ is a partial coefficient of the correlation between X_i and X_j, $(j < i)$ [20].

The construction of the I-distance is an iterative process, which consists of several steps. First, the value of the discriminate effect of the first variable (the most significant variable, which encompasses the highest amount of information on the phenomena upon which the entities will be ranked) is calculated. Then, the value of the discriminate effect of the second variable that is not covered by the first one is calculated. This procedure is repeated for the all observed variables in the data set [21].

Sometimes, when calculating the I-distance, it is possible to encounter different sign marks of variables in the data set. Namely, the negative coefficient of correlation and negative coefficient of partial correlation may occur. To overcome this problem, it is suitable to use the square I-distance [22]. It is given as:

$$D^2(r,s) = \sum_{i=1}^{k} \frac{d_i^2(r,s)}{\sigma_i^2} \prod_{j=1}^{i-1} \left(1 - r_{ji.12...j-1}^2\right)$$

(3)

Although the I-distance method provides ranks, its results are incomparable as it calculates the distance of each entity from the fixed entity. One of the ways to use the obtained results is to create new weights from them. The Composite I-distance methodology (CIDI) establishes adequate weights for the selected indicators [14]. To employ the CIDI methodology, it is necessary to acquire information about the importance of each indicator for the ranking process. The new weights are formed by dividing the Pearson’s correlation coefficient by the sum of correlation coefficients. The formula is given as:

$$w_i = \frac{r_i}{\sum_{j=1}^{k} r_j}$$

(4)

Where ri, (i=1,...,k) is the Person correlation coefficient the i-th input variable and the I-distance value. The sum of weights acquired using CIDI is 1 [6]. The new weighting scheme we propose is unbiased and based on a statistical I-distance method that has previously been used with great success.

Uncertainty analysis tackles the question of the influence of input indicators on the overall result by creating alternative models of the same composite indicator [23]. On the other hand the sensitivity analysis measures the effect of each individual score of the uncertainty analysis. The results of the combined analysis can provide useful information on the impact of indicators to overall scores [24]. In the case of the hybrid approach, these two analysis can be used to evaluate the newly obtained weights. Uncertainty and sensitivity analysis have been previously used with great success in the assessment of composite indicators [25, 26].

Namely, in the case analyzed, the uncertainty and sensitivity of the official index, the index using the CIDI weights [6] and the hybrid index can be compared to confirm the stability of the newly proposed methodology [14]. The uncertainty and the sensitivity analysis performed in this paper are based on the relative contribution that were the input into Monte Carlo simulation to simulate the overall score. The relative contribution can be defined as "a proportion of an indicator score multiplied by the appropriate weight with regard to the overall entity score" [6], while the overall score was simulated 10000 times.

RESULTS

As presented in Section 3, CIDI methodology provides unbiased weights by using the results of the I-distance methodology. We calculated the needed Pearson's correlation coefficients and, therefore, obtained new weights of each pillar's indicators, while we left the pillar weights as proposed by the experts. The results of the CIDI methodology are provided in Table 2.

Table 2 Weightings of input IDI indicators based on I-distance methodology

ICT Access	(a) Pillar weight	(b) Indicator weight	Overall weight (a*b)
1. Fixed-telephone subscriptions per 100 inhabitants		20.22%	8.09%
2. Mobile-cellular telephone subscriptions per 100 inhabitants		17.47%	6.99%
3. International Internet bandwidth (bit/s) per Internet user	40%	19.10%	7.64%
4. Percentage of households with a computer		21.65%	8.66%
5. Percentage of households with Internet access		21.56%	8.62%
ICT Use	**(a) Pillar weight**	**(b) Indicator weight**	**Overall weight (a*b)**
6. Percentage of individuals using the Internet		34.66%	13.86%
7. Fixed (wired)-broadband subscriptions per 100 inhabitants	40%	34.36%	13.75%
8. Wireless-broadband subscriptions per 100 inhabitants		30.98%	12.39%
ICT Skills	**(a) Pillar weight**	**(b) Indicator weight**	**Overall weight (a*b)**
9. Adult literacy rate		34.95%	6.99%
10. Secondary gross enrolment ratio	20%	33.90%	6.78%
11. Tertiary gross enrolment ratio		31.15%	6.23%

If Tables 1 and 2 are compared, we can see how the indicator weights changed after applying the hybrid methodology. In case of the *ICT Access* pillar, indicator *Mobile-cellular telephone subscriptions per 100 inhabitants* dropped its significance from 20% to 17.47%, whereas *Percentage of households with a computer* increased its importance to 21.65%. Looking at the second pillar, the *ICT Use*, CIDI placed less importance on *Wireless-broadband subscriptions per 100 inhabitants*, just 30.98%. Finally, the last pillar, *ICT Skills*, saw the highest improvement of weights: *Adult literacy rate* improved its weight for 1.95 points.

Giving a closer look on the overall weight of indicators, they range from 13.86% (*Percentage of individuals using the Internet*) to 6.23% (*Tertiary gross enrolment ratio*). Such a high weight assigned to indicator *Percentage of individuals using the Internet* can be upheld by the fact that it is one of the indicators for monitoring the Millennium Development Goals (MDGs) which aims at measuring those that used the Internet (both fixed or mobile network) in the last 12 months [27].

Table 3 presents the results of our research, giving the hybrid approach scores and ranks, as well as their comparison to the official IDI scores. The results are shown for 20 top ranked countries.

The provided Table 3 displays the differences between the official IDI rank and the rank obtained following the hybrid approach.

Highest discrepancies can be observed in the case of Macao, China who tops the list from 14th place and in the case of United Kingdom who almost did not enter the top 20 countries from the previously held 8th place. Also, a meaningful rank change is the rank improvement of the United States for 5 places. Other countries went through slight rank shifts.

Table 3 Hybrid approach scores and ranks, and comparison with official IDI scores and ranks for 2012; 20 top ranked countries

Country	Value	Rank	IDI	IDI Rank
Macao, China	10.23	1	7.65	14
Korea	8.71	2	8.57	1
Denmark	8.52	3	8.35	4
Sweden	8.48	4	8.45	2
Iceland	8.47	5	8.36	3
Finland	8.35	6	8.24	5
Norway	8.25	7	8.13	6
Netherlands	8.22	8	8.00	7
Australia	8.15	9	7.9	11
Luxembourg	8.11	10	7.93	9
Hong Kong	8.09	11	7.92	10
United States	8.06	12	7.53	17
Japan	8.01	13	7.82	12
Singapore	7.95	14	7.65	15
Switzerland	7.85	15	7.78	13
New Zealand	7.82	16	7.64	16
France	7.72	17	7.53	18
Germany	7.58	18	7.46	19
United Kingdom	7.55	19	7.98	8
Canada	7.48	20	7.38	20

UNCERTAINTY AND SENSITIVITY

To evaluate the proposed approach and the newly-obtained weights, uncertainty and sensitivity analysis of the official IDI, CIDI by Dobrota and associates [6] and the hybrid IDI have been compared. Figure 2 provides the uncertainty and sensitivity of all three IDI weighting schemes for the 20 first ranked countries while Table 4 provides the frequency matrices of the countries' ranks shift.

Finland, Macao China, Hong Kong, Korea, and Iceland are averagely ranked as top 5 countries according to the original IDI. In case of CIDI and hybrid approach, the list of countries has changed. Namely, Finland and Hong Kong dropped out and were replaced by Sweden and Denmark.

The list of countries in the case of CIDI and hybrid approach has not changed, but there were shifts in ranks. Iceland dropped from 3rd to the 5th rank, while Denmark and Sweden improved their ranks for one place. An interesting result is that Macao, China ranked first in all three observed cases.

Looking at Figure 2, one can see that the results of the Monte Carlo simulation have been evidently improving as the weighting scheme changed. Namely, the official IDI methodology proved to be the most sensitive while the other two approaches showed significantly more stable results. Whereas the hybrid approach displayed the best results so far. In 100% of simulations conducted the countries stayed in the same rank span (Figure 2c).

Besides, Figures 2b and 2c show that all countries have a low degree of sensitivity to the CIDI methodological assumptions and to proposed hybrid approach. Thus, the CIDI, especially the hybrid approach, propose a more stable methodology that decreases the variability of the analyzed ranking system.

Figure 2 Uncertainty and sensitivity of IDI ranks, CIDI ranks using the approach of [6] and the proposed hybrid approach ranks

a) IDI ranks b) CIDI ranks c) Hybrid approach ranks

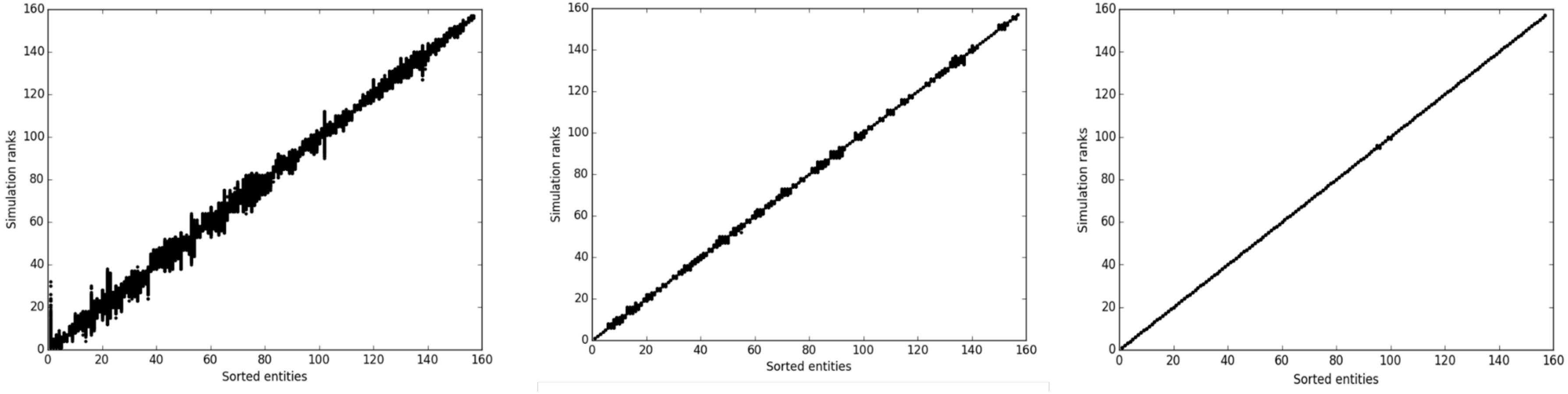

Table 4 Uncertainty and sensitivity analysis of IDI ranks, CIDI ranks [6] and the proposed hybrid approach ranks

a) IDI ranks b) CIDI ranks c) Hybrid approach ranks

Country	1-5	6-10	11-15	16-20	21-25	26-35
Macao, China	9665	257	31	33	11	3
Finland	10000					
Hong Kong	9905	95				
Korea	9955	45				
Iceland	9979	21				
Sweden	142	9858				
Denmark	350	9650				
Netherlands		9998	2			
Norway	3	9814	183			
Australia		8979	1008	13		
New Zealand		206	9790	4		
United Kingdom		14	9970	16		
United States		195	8680	1125		
Switzerland	1	692	9036	271		
Austria			8181	1819		
Luxembourg		167	2652	6687	470	24
Belgium		9	167	9560	264	
Spain			12	8876	1112	
Ireland				9351	649	
Slovenia			3	4647	4952	398

Country	1-5	6-10	11-15	16-20	21-25
Macao, China	10000				
Korea	10000				
Iceland	10000				
Denmark	10000				
Sweden	10000				
Finland		10000			
Netherlands		10000			
Hong Kong		10000			
Australia		9954	46		
Norway		9969	31		
Luxembourg		77	9923		
United Kingdom			10000		
Switzerland			9995	5	
Japan			10000		
New Zealand			9989	11	
Singapore			16	9984	
France				10000	
Germany				10000	
United States				10000	
Canada				6012	3988

Country	1-5	6-10	11-15	16-20
Macao, China	10000			
Korea	10000			
Denmark	10000			
Sweden	10000			
Iceland	10000			
Finland		10000		
Norway		10000		
Netherlands		10000		
Australia		10000		
Luxembourg		10000		
Hong Kong			10000	
United Kingdom			10000	
Japan			10000	
Singapore			10000	
Switzerland			10000	
New Zealand				10000
France				10000
Germany				10000
United States				10000
Canada				10000

The two performed analysis show that the even though the results obtained by Dobrota and associates [6] provided an important step towards improving the IDI ranking methodology, the hybrid approach proved to be more consistent and trustworthy. The differences in stability in Figures 2a and 2c are evident meaning that the mix of biased and unbiased approach to weighting can provide meaningful results.

DISCUSSION AND CONCLUSION

The weighting process raises many problems and questions in a CI. As various stakeholders have incorporated such metrics in the decision making process, it is of exceptional importance to provide rankings as accurately as possible [20]. Therefore, we created a fusion of biased and objective weighting methods. Namely, the CI provided this way allows a more precise measurement of the observed phenomena. It limits the influence of the experts, by giving them freedom only to define the pillar weights and not the overall weighting scheme. The presented example of scrutinizing the IDI using the hybrid approach showed the fusion of methods provides more stability with less objectiveness.

Future directions of the study could tackle the question which indicator level weights should be subjective and which should be objective. Herein, we decided to make the weights for aggregating indicators to pillars objective while leaving the weights of pillars to overall result subjective. Nevertheless, it could have been the other way around. Therefore, one of the proposed future studies could be the comparison of the two hybrid approaches. Another direction of the future studies can be the reduction of the index indicators. Post hoc I-distance approach can be used to solve this issue [28]. Also, a multivariate approach to the hybrid approach could be of interest. Following the idea of Ayanso and associates [15], who performed clustering analysis of IDI, the same analysis could be done based on the newly obtained results. It would interesting to compare the results and analyze how the clusters changed when another weighting scheme was applied.

There are several contributions of this study that should be pointed out. First, it introduces a novel approach for assigning weights when creating a CI. Secondly, it uses the CIDI methodology, which overcomes the common limitation of CIs, the bias of the assigned weights to its indicators. Finally, the model incorporates expert opinion. The presented approach could be a foundation for further research on weighting schemes which tends to take into account both approaches to assigning weights: the biased and the unbiased approach.

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