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Research Article

ENTROPY WEIGHT METHOD FOR EVALUATING INDICATORS OF ICT DEVELOPMENT INDEX

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A B S T R A C T

In the design of any study based on the concept called information entropy, a means of collecting data was used. Entropy, in information theory, is a property of the mean variance of a random variable. These measures are monitored by determining, assessing, and using the entropy-based method and are ICT indicators of the information society. The proposed approach is defined as a weight of indicators in the ICT development index and the sub-indexes. In this paper, we firstly investigate availabilities of information entropies and entropy weighting method. Secondly, we determine information entropy and entropy weights of ICT development index indicators. Finally, some numerical results of the methodology are presented.

INTRODUCTION

The ICT Development Index (IDI) is an index that combines eleven indicators into one benchmark, and since 2009 has been published annually. It is used over time to track and compare developments in ICTs among countries [1, 2]. The IDI is divided into three sub-indexes: access sub-index, using sub-index and sub-index abilities, each capturing particular aspects and components of ICT development process. The sub-index is given various weights in the calculation of the IDI. The combination weights will compromise objective weights. In this paper we propose a sub-index weight taking into account the parameters of the ICT measure for evaluating the IDI. An entropy-based weighting method is an integration of a novel entropy-based approach that combined the bootstrap method, entropy weight coefficient method.

The information theory is a mathematical representation of the parameters and conditions that affect the processing of communication. Information theory is closely related to communication theory, but it is more familiar with the fundamental limitations in the field of communication and information processing and is less well known with regard to the detailed operation of specific devices. Information theory is part of applied electrical engineering and mathematics, which includes calculation of information.

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The information theory was developed by Shannon to determine the fundamental constraints on compression and reliable data. Information theory is based on statistics and probability theory.

The remaining paper is organized as follows: in Section 2, the methodology of index evaluation and weighting method are introduced. Section 3 discusses the results of the weighing method case study to demonstrate decision effectiveness and the outcomes analysis. The last section is the conclusion.

Entropy Weight Method

The work on information theory of Claude E. Shannon in the middle of the 20th century is mainly of interest to communication engineers. In 1948 paper named "A Mathematical Theory of Communication The concept of information entropy" was submitted by Shannon [3]. Shannon pointed out that the measure is valid only if all events are equiprobable [3]. Shannon presented the information entropy, based on the thermodynamic principle, where entropy is the degree of molecular breakage in matter for the first time. It was used as a measure of disorder, uneven distribution, dependence degree or complexity of the system [4]. Entropy weighing is a method that consists of monitoring values of the evaluation index under objective conditions, can determine the purpose and order degree and efficiency, referring to the information entropy estimate. The entropy weight from entropy weighting method make ranks lists more objective and evaluation weight coefficient [5]. This avoids the subjectivity of the weights of the various criteria, and therefore the results of the evaluation may better reflect the real situation [6]. To avoid subjective opinion, the model is built from measured index, where the entropy weights were determined from Shannon's theory of entropy [7-10]. There are the following specific steps:

Suppose that there are some things that need to be evaluated, their number is *m*. There is an object of evaluation n objects. The determining matrix of the evaluation model must be established.

$$R_{ij} = (x_{ij})_{mxn} \tag{1}$$

Where R is the matrix, x_{ij} is the matrix elements. x is the value of the j^{th} sample of the i^{th} indicator.

This requires normalization. Actual operations:

$$\begin{cases} d_{ij} = x_{ij} / max \;\; x_{ij}, positive \;\; indicators \\ d_{ij} = x_{ij} / min \;\; x_{ij}, negative \;\; indicators \end{cases} \tag{2}$$

The new space matrix:

$$D_{ij} = (d_{ij})_{mxn} \tag{3}$$

The relative weight of x_{ij} is:

$$Y_{ij} = (y_{ij})_{mxn} \tag{4}$$

$$y_{ij} = d_{ij} \Big/ \sum_{i=1}^{m} d_{ij}$$

Assume that there are estimating factors by *m*, estimating objects counted n, then forms an element matrix $R_{ij}=(r_{ij})mxn$, Since entropy has an extreme property [11], [12], the smaller the value of r_{ij} deviates from the equal, the more entropy there is, and the greater the uncertainty of the estimate. Information entropy, which is based on the definition of entropy of the i^{th} indicator of the evaluation matrix *Y* is defined by Equation (5):

$$E_i = -\frac{1}{\ln n} \sum_{j=1}^{n} y_{ij} \ln y_{ij} \tag{5}$$

In addition, k-positive constant, determining $k=1/ln(n)$, which is a normalizing positive constant for maintaining $0 \le Ei \le 1$.

The weight is calculated from the utility value of the index information defined by the entropy weight method. The utility value is the largest of the estimate.

The weight of i^{th} index is determined by Equation (6):

$$w_i = \frac{1 - E_i}{\sum_{i=1}^{m} (1 - E_i)} \tag{6}$$

Computing results of equation (6) are used for extraction indicators [8]. Those measurements of equations are used for weights of entropy. In analyze information entropy weight common is used those equations 1-6. The entropy analyzes based on independent probability or independent each other of ICT indicators.

Analysis of IDI Indicator

The model built from measured index data is following equations 1-6 of specific series steps for calculation. The evaluation criterion can be classified as an increasing or decreasing type depending on its attributes.

These equations calculations are used for evaluation of IDI indicators. This section conducts an exhaustive evaluation of the IDI data of Asia pacific region countries [13-16].The index is conceived to be represent and global changes occurring in countries at various rates of ICT growth. Hence, it relies on a collection of data that can be developed in each countries at all rates of development with good confidence. To accept that ICTs could be enablers of development and is essential to the conceptual meaning of IDI. The IDI consists of three sub-indexes, and eleven indicators, based on this conceptual structure [13-16]. (Table 1). The IDI indicator weight by ITU methodology are defined sub-indexes of access and usage were given equal weight in IDI and ICT indicators weight in sub-indexes. Sub-indexes of access and usage were given equal to 40 per cent of each weight. Less weight 20 per cent was assigned to the sub-index of skills, as it is based on proxy indicators. Weights of the indicators are chosen based on the study results of the ICT indicators [17]. Assume there are some things need to be evaluating, their number is 11 IDI indicators. There are objects are presented 34 Asia pacific countries [2, 18-20]. The ITU Secretariat recommends publishing the IDI for 2019 on the basis of the original methodology and set of indicators, rather than publishing it in any way [21, 23]. And we used IDI data for 2017 and pre-2017. Entropy and entropy weight of IDI indicators are defined according to equation 5, 6 [24, 25].

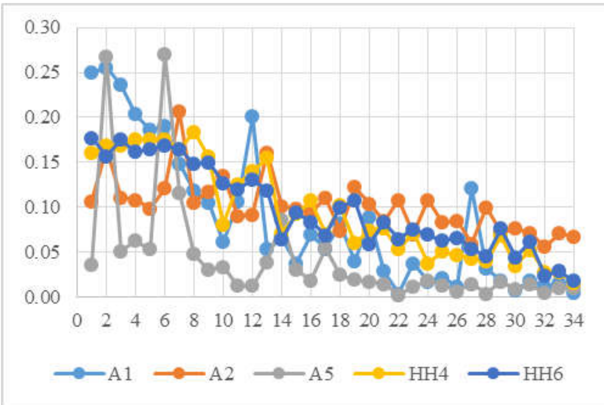

Figure 1 Entropy values of IDI access sub-index of Asian countries

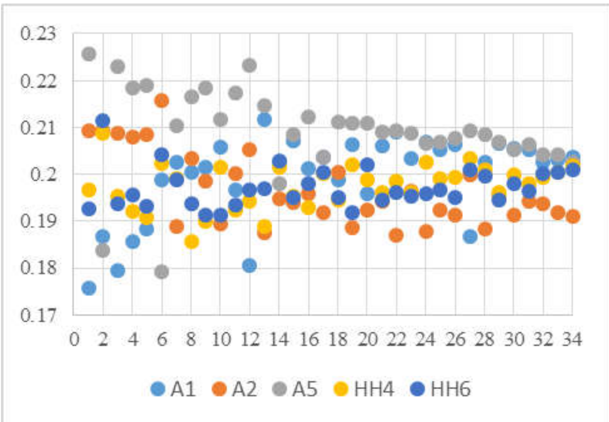

Figure 2 Entropy weight values of IDI access sub-index of Asian countries

Figure1 shows entropy values of A1, A2, A5, HH4 and HH6 indicators of IDI access sub-index of Asian countries. Horizontal axis values indicate the number of Asian countries by rank of IDI [19, 20]. Entropy of A1-fixed-telephone subscriptions per 100 inhabitants carried a value of 0.004 to 0256. Entropy of A2-mobile cellular telephone subscriptions per 100 inhabitants held a value between 0.056 and 0.206. Entropy of A5-international internet bandwidth (bit/s) per internet user carried a value of 0.002 to 0.27. Entropies HH4-percentage of households with a computer have a value of 0.015 to 0.184. Entropy HH6-percentage of households with internet access have maintained a value from 0.018 to 0.117.

Table 1 ICT Development Index: indicators and weights

Indicators	code	%	%
Access ***sub-index***			
Fixed-telephone subscriptions per 100 inhabitants	A1	20	
Mobile-cellular telephone subscriptions per 100 inhabitants	A2	20	
International Internet bandwidth (bit/s) per Internet user	A5	20	40
Percentage of households with a computer	HH4	20	
Percentage of households with Internet access	HH6	20	
Usage sub-index			
Percentage of individuals using the Internet	HH7	33.33	
Fixed-broadband subscriptions per 100 inhabitants	A3	33.33	40
Active mobile-broadband subscriptions per 100 inhabitants	A4	33.33	
Skills *sub-index*			
Mean years of schooling rate	S1	33.33	
Secondary gross enrolment ratio	S2	33.33	20
Tertiary gross enrolment ratio	S3	33.33	

Figure 2 illustrates entropy weight values of IDI access sub-index of Asian countries. Maximum entropy weight value is 0.226, minimum entropy weight value is 0.176 of access sub-index indicators of IDI. Figure 3 shows entropy values of HH7, A3, A4 indicators of IDI use sub-index of Asian countries. Entropy of HH7- percentage of individuals using the internet carried a value of 0.004 to 0.256.

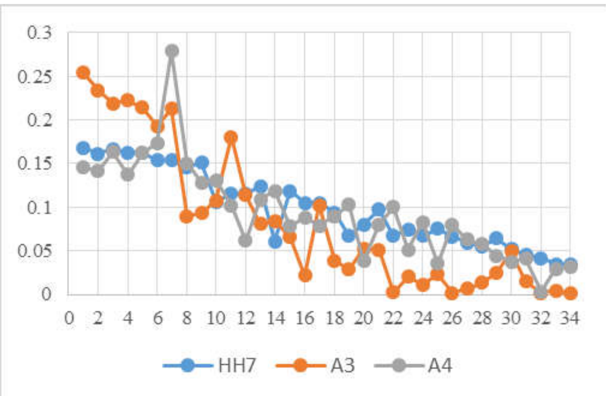

Figure 3 Entropy values of IDI use sub-index of Asian countries

Entropy of A3-fixed-broadband subscriptions per 100 inhabitants value covered ranges from 0.056 to 0.2539. Entropy A4-active mobile-broadband subscriptions per 100 inhabitants covered ranges as 0.008 to 0.1279.

Figure 4 shows entropy weight values of IDI use sub-index of Asian countries. Maximum entropy weight value-0.359, minimum entropy weight value-0.306 of use sub index indicators of IDI.

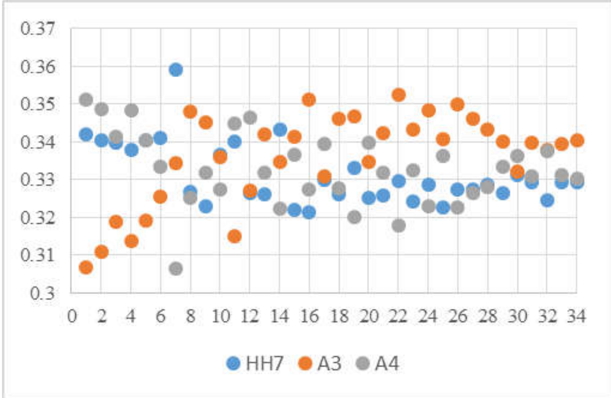

Figure 4 Entropy weight values of IDI use sub-index of Asian countries

Figure 5 shows entropy values of mean years of schooling rate, secondary gross enrolment ratio, tertiary gross enrolment ratio indicators of IDI skills sub-index of Asian countries.

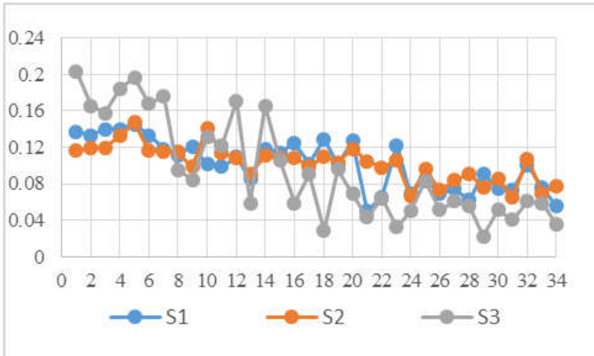

Figure 5 Entropy values of IDI skills sub-index of Asian countries

Entropy of S1- mean years of schooling rate covered as 0.05 to 0145. Entropy of S2-secondary gross enrolment ratio covered between 0.065 and 0.147.

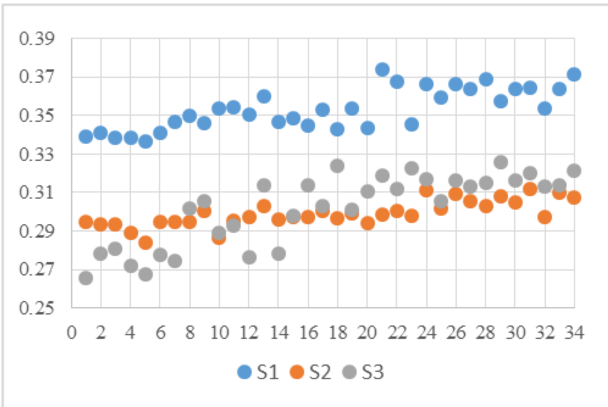

Figure 6 Entropy weight values of IDI skills sub-index of Asian countries

Table 4 Difference indicators and sub-indexes percentages

IDI indicators	%	%	Difference indicators percentages	%	%	Difference sub-index percentages
			Accesssub-index			
A1	20	19.95	0.05			
A2	20	19.66	0.34			
A5	20	20.92	0.92	40	45.77	5.77
HH4	20	19.75	0.25			
HH6	20	19.71	0.29			
			Usagesub-index			
HH7	33.33	33.13	0.2			
A3	33.33	33.6	0.27	40	27.21	12.79
A4	33.33	33.26	0.07			
			Skillssub-index			
S1	33.33	35.33	2			
S2	33.33	29.91	3.42	20	27.02	7.02
S3	33.33	30.16	3.17			

Entropy S3-tertiary gross enrolment ratio carried a value of 0.008 to 0.1279. Figure 6 shows entropy weight values of IDI skills sub-index of Asian countries. Maximum entropy weight value is 0.37 and the minimum entropy weight value is 0.265 of skills sub-index indicators of IDI. Table 4 contains the difference percentages weights of IDI sub-indexes between ITU methodology of IDI and entropy weight method by each indicator and sub-indexes. Results of difference indicators (0.05-0.92)% in access sub-index, (0.07- 0.27)% in usage sub-index, (2.0-3.42)% in skills sub-index, and sub-indexes (5.8-12.79)% in IDI. Therefore, IDI indicators weights and reference value need study analysis.

Table5 displays IDI sub-indexes indicator weights with ranking by ICT indicator coefficient by ITU methodology and entropy weight method. Weights using ICT indicator coefficient by ITU methodology included percentages and reference values of sub-index indicators. In access sub-index A2 indicator weight is 0.167. A5 indicator weight is 2.45. In usage sub-index A3 indicator weight is 0.56, HH7 and A4 indicator weights are 0.33. In skills sub-index S2 and S3 indicator weights are 0.033. S1 indicator weight is 0.22.

Table 5 IDI sub-indexes indicator weights with ranking

ICT indicator	ICT indicator coefficient by ITU methodology	Rank	W	rank
	Access sub-index			
A1	0.3333	1	0.1995	2
A2	0.1667	5	0.1966	5
A5	2.4547	2	0.2092	1
HH4	0.2	3,4	0.1975	3
HH6	0.2	3,4	0.1971	4
	Usage sub-index			
HH7	0.3333	2,3	0.3313	3
A3	0.5556	1	0.336	1
A4	0.3333	2,3	0.3326	2
	Skills sub-index			
S1	0.2222	1	0.3533	1
S2	0.0333	2,3	0.2991	3
S3	0.0333	2,3	0.3016	2

The assessment result listed in Table 6 indicates the IDI indicators for rankings by ITU methodology of A5 indicator is the first and S2, S3 indicators are the 10^{th} and 11^{th}.While for the entropy weight method performance the best one is A5 indicator and S2 indicator is 11^{th} ranking.

Table 6 Evaluation value and weights coefficients information IDI with ranking

Region, number of countries	IDI indicator coefficient by ITU methodology	rank	W	rank
A1	0.0133	3,4,5	0.0913	3
A2	0.0067	8	0.0900	9
A5	0.0982	1	0.0958	1
HH4	0.008	6,7	0.0904	6
HH6	0.008	6,7	0.0902	7
HH7	0.0133	3,4,5	0.0901	8
A3	0.0222	2	0.0915	2
A4	0.0133	3,4,5	0.0905	4
S1	0.0044	9	0.0899	10
S2	0.0007	10,11	0.0899	11
S3	0.0007	10,11	0.0904	5

CONCLUSIONS

An index evaluation method for the calculation of IDI by regions and countries is proposed in this paper. These studies include defining the weight of IDI indicators based on the entropy weight method. This paper outlines the methods used to evaluate the IDI indicators. The weight of the IDI indicators is fairly simple to obtain, while the entropy weight theory focuses on the relative position of each ICT indicator data set.

The execution for computing the entropy and entropy weight of IDI indicators will be given in accordance with the formulas given above. Research analysis of IDI indicators' weights and reference values are required. This evaluation considers eleven ICT indicators of IDI. However, the methodology we proposed in this paper can be used regardless of the changing number of ICT indicators in the access, usage and skills sub-indexes.

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