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REDESIGNING THE GLOBAL FOOD SECURITY INDEX: A MULTIVARIATE COMPOSITE I-DISTANCE INDICATOR APPROACH

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Abstract

The topic of food security has gained significant attention and importance due to its impact on political, economic, and humanitarian decisions governments make. Although composite indexes that measure food security have proliferated in the last decade, many questions regarding their methodologies remain unanswered. Among several composite indexes that aim to measure food security, the Global Food Security Index (GFSI) stands out for its solid methodology and reliable data sources. However, its weighting scheme can be categorized as biased. This paper attempts to overcome the issue of subjectively assigned weights to indicators and categories within the GFSI. Namely, we propose a statistical methodology, the Composite I-distance Indicator (CIDI), which is based on the I-distance method, for obtaining an unbiased weighting scheme. Our approach can serve as a foundation for future research on weighting schemes, which are enveloped with subjectivity.
Keywords: *Global Food Security Index, I-distance method, Ranking of countries, CIDI methodology, Weighting scheme*

1. Introduction

The global population is expected to grow in the years to come; therefore, the world will be facing new intersecting challenges, whereas the ones regarding the food production will especially stand out (Evans, 2009). The most important ones related to food production are: *matching* the growing and changing demand for food in a *sustainable* way, still making it affordable and available so no one would experience *hunger* (Von Braun, 2007). Recent studies suggest that the world will need 70 to 100% more food in the next 40 years (Baulcombe et al., 2009). The agriculture is expected to find a way to answer to such a high demand with scarce or reduced inputs. A daunting task is put upon natural and social sciences which are to team up to revolutionize the food production (Carpenter et al., 2009; Godfray et al., 2010). Most related research solely focuses on agricultural production, or the consequences of agriculture on land use, biodiversity and pollution (Ericksen, Ingram, & Liverman, 2009). No matter how important the food production is, there are many other aspects of food and nutrition that should be tackled, such as food security (Tester & Langridge, 2010).

Food security is an issue of growing interest. It is defined as "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 1996). Another approach to defining food security is through food availability, access, utilization, and stability (Stamoulis & Zezza, 2003). Although there are few definitions of food security, there is need for a more sophisticated and unifying understanding of the concept (FAO, 2008). Nevertheless, considering the widely accepted definitions, food security can be recognized as a universal human right (FAO, 2005), and a multidimensional phenomenon (Godfray & Garnett, 2014). Therefore, we can conclude that food security is a delicate and sentitive issue, which should be tackled with great attention.

Having all the above-presented in mind, a need for measuring food security on the national level emerged for mostly two reasons. Firstly, some of the topics covered by the broad definition of food security can be classified as targets of the United Nations (UN) Millennium Development Goals (MDGs). This makes food security a subject for countries to be compared against each other. Secondly, governments have acknowledged the important role that food security is playing, not only in the food production systems, whereas in upholding the country's socioeconomic stability (Barling, Lang, & Caraher, 2002). Also, governments await return information on the success or failure of their polices and investements in reducing food insecurity. Accordingly, numerous food security indicators and indexes have been recently proposed (for example see Headey & Ecker, 2013; Morón & Viteri, 2009). However, a study by Leroy and associates (2015) proved that no single indicator could be used to assess food security due to its complexity, and that a set of indicators could be more adequate. Their study acts as a proof that composite indicators should be employed to measure food security.

Dogliotti and associates (2014) reported that one of the conclusions of the First International Conference on Global Food Security was that a systematic approach to analysis, data, models, and metrics is needed. On the same topic, Santeramo (2015a), in his detailed study on composite indexes of food security, puts a clear emphasis on the issues such measures encounter. Namely, the first is the inconsistency of the definition of food security itself, followed by the theoretically unsupported or unelaborated indicator selection process, and the not always straightforward aggregation methodology. It is, therefore, of high significance to create a statistically sound method to measure the food security or try to alter the currently devised ones.

A rather simple categorization of recently developed composite indexes on food security divides them by the scale on which they measure food security and by the specific food security domain they aim at measuring (Jones et al., 2013). For example, Global Hunger Index (GHI) is designed to measure hunger (*Availability*) on country and national level (International Food Policy Research Institute, 2015), while the Household Food Insecurity Access Scale (HFIAS) measures the impacts of development food aid programs on the *Access* component of household food insecurity (Coates, Swindale, & Bilinsky, 2007). An index which stands out is the Global Food Security Index (GFSI) for it measures all three main concerns of food security (*Access*, *Availability* and *Utilization*) on a global scale (EIU, 2015). However, its weighting scheme relies on expert opinion, which makes its results and ranks questionable.

Thus, in this paper we propose the Composite I-distance Indicator (CIDI) methodology, which can upgrade the measuring process in a composite index (Dobrota et al., 2015a), as a method of reducing the level of bias of the GFSI weighting scheme. The following chapter sees the introduction of GFSI while the CIDI methodology will be elaborated in detail in Section 3, along with the concept of uncertainty and sensitivity analyses. The results are given in Section 4, while the uncertainty and sensitivity results, used to evaluate the obtained weights shall be elaborated in Section 5. The concluding remarks are provided in the final chapter.

2. Global Food Security Index (GFSI)

The Global Food Security Index (GFSI) is a multidimensional measurement of the level up to which countries provide safe food to their citizens. It was developed by The Economist Intelligence Unit and sponsored by DuPont. The GFSI 2015, which will be analysed in this research paper, is the fourth edition of the index (EIU, 2015). The aim of the index is to rank and compare countries by using 28 indicators divided into three categories: *Affordability, Availability,* and *Quality and Safety* (a detailed list of indicators which make each of the three categories is listed below in Table 1).

The *Affordability* category aims at exploring the capacity of country's residents to purchase food. Besides analysing the purchasing power of residents and pricing, this category takes into account the *Presence of food safety-net programmes* and the government expenditure on projects that encourage local farming.

Food availability can be broadly defined as "*a measure of food that is, and will be, physically available in the relevant vicinity of a population during a given period*" (Hoddinott & Yohannes, 2002). The GFSI *Availability* category reflects the government's role and the effects of their decisions on the food production process.

Besides measuring the impact of factors on food production and food purchase, it is necessary to analyse the nutritive composition of the purchased food (Hoddinott & Yohannes, 2002). Therefore, the final category *Quality & Safety* assesses the nutritional structure of the average diet and the food safety. The issue of measuring the nutrient intake has become central to policy agendas of both governmental and non-governmental organizations. Therefore, its inclusion in the composite index is of high importance (Santeramo & Khan, 2015). This category is mainly oriented to individuals, whereas it analyses their energy and nutrient intake. However, it also aims at measuring the country's efforts to provide its citizens with clean, potable water and a formal and secure grocery sector (EIU, 2015).

What makes the GFSI stand out from other similar metrics is that it takes into account qualitative and quantitative indicators that aim to depict three aspects of food security: food availability, food access, and diet quality (Jones et al., 2013). Moreover, the GFSI relies on respectable data sources like the Economist Intelligence Unit, the World Bank, FAO, World Food Programme (WFP), and the World Trade Organization (WTO). Also, unlike other composite indexes on food safety, the GFSI is calculated for 109 countries, providing results for both developed and developing countries (Pangaribowo, Gerber, & Torero, 2013). One of the main drawbacks of this metric is that 8 out of its 28 indicators are calculated by qualitative scoring by EIU analysts. These measures may present a potential threat to the quality and the credibility of the index (Jones et al., 2013). Also, as mentioned, its weighting scheme was created using a subjective method – panel recommended weighting.

The index categories are formed of indicators, where some of the indicators have sub-indicators. In our analysis, we will not take into account the lowest level (the sub-level) of the indicator. More precisely, we will analyse the weighting scheme of indicators to categories, and categories to the overall result. Indicator values, which derive from several indicators, will be taken as provided in the official dataset. Table 1 provides indicators and weights used to calculate the GFSI that will be scrutinized further in the paper.

Taking a closer look at the current weighting scheme (Table 1), one can note the categories are not weighted equally or in a balanced way. The question that arises is whether such a weighting scheme is in accordance with the definition of food security and can one category be more than twice important than the other (*Availability* vs. *Quality and Safety*). Availability does not secure access, and sufficient calories do not guarantee a nutritive and a diverse diet (Pinstrup-Andersen, 2009). Also, weights within categories significantly vary. Special attention should be placed on the effective weights of individual indicators. According to the presented weighting scheme indicator *Sufficiency of supply* proves to be the most significant for the ranking process, as it is awarded with weight of 10.30%. On the other hand, all indicators of the category *Quality and Safety* have been assigned effective weights below 5%.

Table 1. Global Food Security Index: Indicators and Weights[*]

1. Affordability	(a) Weight within GFSI	(b) Weight within Affordability	Overall weight (a*b)
1.1 Food consumption as a share of household expenditure	40%	22.22%	8.9%
1.2 Proportion of population under the global poverty line		20.20%	8.1%
1.3 Gross domestic product per capita (PPP)		22.22%	8.9%
1.4 Agricultural import tariffs		10.10%	4.0%
1.5 Presence of food safety-net programmes		14.14%	5.7%
1.6 Access to financing for farmers		11.11%	4.4%
2. Availability	(a) Weight within GFSI	(b) Weight within Availability	Overall weight (a*b)
2.1 Sufficiency of supply	44%	23.42%	10.30%
2.2 Public expenditure on agricultural R&D		8.11%	3.57%
2.3 Agricultural infrastructure		12.61%	5.55%
2.4 Volatility of agricultural production		13.51%	5.94%
2.5 Political stability risk		9.91%	4.36%
2.6 Corruption		9.91%	4.36%
2.7 Urban absorption capacity		9.91%	4.36%
2.8 Food loss		12.61%	5.55%
3. Quality and Safety	(a) Weight within GFSI	(b) Weight within Quality and Safety	Overall weight (a*b)
3.1 Diet diversification	16%	20.34%	3.25%
3.2 Nutritional standards		13.56%	2.17%
3.3 Micronutrient availability		25.42%	4.07%
3.4 Protein quality		23.73%	3.80%
3.5 Food safety		16.95%	2.71%

[*]**Note:** only the indicators and weights of the analysed levels of GFSI are presented

The weighting scheme employed in the default model on both category and indicator level is a panel recommended weighting scheme while the aggregation method is the simple weighted sum. Panel members are renowned experts on food security from institutions like the World Bank, US Agency for International Development, Earth Institute, Columbia University, and others (EIU, 2015). Nevertheless, the GFSI weighting scheme can be, according to Booysen (2002), classified as a subjective one. As such, it makes the GFSI results questionable. The idea behind this paper to attempt to enhance the GFSI, thus making its weights less biased, more objective and dependent from the collected data. To perform such a task, we propose the CIDI methodology, which can provide unbiased weights and reduce the instability of the analyzed index.

3. Methodology

3.1. I-distance method

Weights and the weighting process play a crucial role in the process of creating a composite index (Nardo et al., 2005a). What additionally makes this process difficult is the fact that there is no agreed and optimal methodology to aggregate individual indicators (Nardo et al., 2005b). Therefore, weighting method is always a controversial issue (Cherchye et al., 2007).

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 (1977), 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 (Jeremic et al., 2013). In order to rank the 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 (Jovanovic-Milenkovic et al., 2015). In our analysis, the referent entity was the one with the minimal values.

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

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

where $d_i^2(r,s)$ is the distance between the values of variable X_i for e_r and e_s e.g. the discriminate effect:

$$d_i^2(r,s) = (x_{ir} - x_{is})^2 \quad i \in \{1, \dots k\} \tag{2}$$

σ_i^2 is the variance of X_i, and $r_{ji.12\dots j-1}$ is a partial coefficient of the correlation between X_i and X_j, $(j < i)$ (Radojicic & Jeremic, 2012). $D^2(r,s)$ represents the square I-distance value of the observed intitiy compared to the fictive entity. At the same time, it is the agregated value of all variables that entered the procedure.

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 (Jovanovic-Milenkovic et al., 2015).

What also makes the I-distance method stand out is its lack of bias. Using the I-distance method when creating a composite index one can overcome the limitation of subjectively assigned weights. Namely, the method does not place any weighting factor on its variables (Jeremic et al., 2014) meaning subjectively assigned weights cannot influence the final ranking of entities. Alongside, Pearson's correlation coefficient can be used to measure the importance of each variable for the ranking process (Jovanovic et al., 2012). Namely, Pearson's correlation coefficient accounts for the proportion of the variability between two variables (Hauke & Kossowski, 2011), therefore it can point out variables which mostly contribute to the overall I-distance value.

Consult the Appendix for more information on how the I-distance is calculated.

3.2. Twofold I-distance approach

To aggregate the framework's indicators, the I-distance method can be applied directly on all index indicators or it can be applied in steps, following the index structure. Namely, the twofold I-distance approach, which we employed in this research paper, consists of two steps. First, we applied the I-distance method on indicators of each category and by so we gained an insight of each category's dynamics. Secondly, again the I-distance method was applied, but now on the previously obtained category results to calculate the Total I-distance value. One should have in mind that I-distance could have been implemented directly to all framework indicators. However, by so, a certain amount of information could have been lost. The proposed framework, together with the correlation coefficients, can be seen in Figure 1.

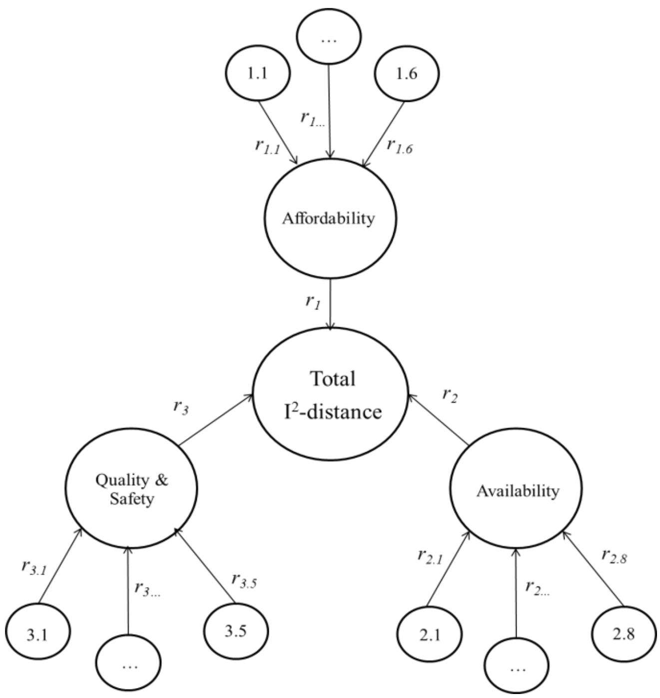

Figure 1. The Proposed Framework and Correlation Coefficients

Not all observed variables possess the same amount of information of the measured phenomena; i.e., not all variables have the same importance for the ranking process (Jeremic et al., 2014). Accordingly, the question of each variable's significance in the analyzed data set arises. On Figure 1 one can note that Pearson's correlation coefficients of each indicator with their category and each category with the Total I-distance value have been determined. The level of the obtained correlation provides additional information about the importance of each indicator and category for the ranking process. Namely, besides just aggregating variables, I-distance method is able to determine the relevance of the input criteria and so to clearly point out variables which are important for their contribution to the final rank (Jeremic et al., 2013).

3.3. Composite I-distance methodology (CIDI)

The Composite I-distance methodology (CIDI) is a methodology of creating a composite index employing the results of the I-distance method. Namely, the results of the I-distance method are incomparable with the official index results as they represent distances from the fictive entity. The CIDI methodology creates a comaprable metric, which follows the original structure of the revised index, using the weights which derive from the I-distance method. Therefore, the next step in the CIDI methodology after performing the I-distance method is to calculate the new indicator/category weights using the obtained results (Dobrota et al., 2015b). To establish new weights, it is necessary to acquire information about the importance of each indicator for the ranking process. Subsequently, we determined the Pearson's correlation coefficients mentioned in the previous subsection.

The new weights are formed by dividing the Pearson's correlation coefficient by the sum of correlation coefficients. The formula is given as:

$$w_i = \frac{r_i}{\sum_{j=1}^{k} r_j}, \tag{3}$$

Where $r_{i,}$ (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 (Dobrota et al., 2015a). Although the election of CIDI methodology to enhance any composite index is subjective, the new weighting scheme we here propose is unbiased in terms it derives from the collected data, and that no expert opinion has been included in the weighting process.

3.4. Uncertainty and Sensitivity Analysis

As mentioned above, some of the steps in the creation of a composite index are covered with the veil of uncertainty. In this paper, we limit ourselves to evaluating the uncertainty of indicator and category weights. Two combined statistical tools are recommended to assess this issue: uncertainty analysis and sensitivity analysis (Saisana, Saltelli, & Tarantola, 2005).

Uncertainty analysis tackles the question of the influence of input indicators on the overall result while 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 (Saisana & D'Hombres, 2008).

In the case of CIDI, these two analyses can be used to evaluate the newly obtained weights. Namely, the uncertainty and sensitivity of the official index and the index using the CIDI weights can be compared to confirm the stability (instability) of CIDI ranks (Dobrota et al., 2015a; 2015b).

The uncertainty and sensitivity analysis performed in this paper are based on the relative contribution which 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"* (Dobrota et al., 2015a) while the overall score was simulated 10.000 times.

4. Results

As elaborated in Section 3.3, CIDI methodology can be used to obtain unbiased weights. As the aim of the paper is to scrutinize the GFSI weighting scheme, the previously presented methodology was employed. First, we used the twofold I-distance approach and calculated the needed Pearson's correlation coefficients. Secondly, we applied the CIDI methodology. Table 2 presents the newly formed weighting scheme.

Table 2. Weights of GFSI Indicators Based on the CIDI Methodology

1. Affordability	(a) Weight within GFSI	(b) Weight within Affordability	Overall weight (a*b)
1.1 Food consumption as a share of household expenditure	33%	14.40%	4.75%
1.2 Proportion of population under the global poverty line		14.70%	4.85%
1.3 Gross domestic product per capita (PPP)		19.50%	6.44%
1.4 Agricultural import tariffs		19.10%	6.30%
1.5 Presence of food safety-net programmes		15.90%	5.25%
1.6 Access to financing for farmers		16.40%	5.41%
2. Availability	(a) Weight within GFSI	(b) Weight within Availability	Overall weight (a*b)
2.1 Sufficiency of supply	31%	11.30%	3.50%
2.2 Public expenditure on agricultural R&D		8.90%	2.76%
2.3 Agricultural infrastructure		15.90%	4.93%
2.4 Volatility of agricultural production		12.10%	3.75%
2.5 Political stability risk		14.60%	4.53%
2.6 Corruption		14.00%	4.34%
2.7 Urban absorption capacity		9.40%	2.91%
2.8 Food loss		13.80%	4.28%
3. Quality and Safety	(a) Weight within GFSI	(b) Weight within Quality and Safety	Overall weight (a*b)
3.1 Diet diversification	36%	20.80%	7.49%
3.2 Nutritional standards		16.70%	6.01%
3.3 Micronutrient availability		19.60%	7.06%
3.4 Protein quality		22.40%	8.06%
3.5 Food safety		20.50%	7.38%

Comparing official weights presented in Table 1 and the obtained results from Table 2, one can note there are substantial differences. When analyzing the new weighting scheme on the category level, we can see that the CIDI method suggests balanced weights. Such a distribution of weights is in accordance with the FAO definition of food security. The category *Availability* went through the largest changes: its weight declined from 44% to 31%. Although the availability of food is important, without enough income to afford it and a certain level of food quality and nutritional standards, its relevance declines. On the other hand, the significance of the category *Quality & Safety* rose from 16% to 36%. Although the three concepts are inherently hierarchical (Webb et al., 2006), higher values of one food security aspect cannot substitute the deficiency of other(s) (Barret, 2010). Therefore, more balanced weights are recommended.

When it comes to analysing the indicator weight changes, in the category *Affordability* the indicator with the largest weight increase is *Agricultural import tariffs,* which is now 19.10%. Within the same group of indicators, CIDI assigned 7.82 points lower weight to the indicator *Food consumption as a share of household expenditure.* The indicator *Sufficiency of supply,* from the category *Availability,* saw the highest decline in weight, from 23.42 to 11.30. The indicators of the last category also experienced changes, whereas the most significant is the lower significance of the indicator *Micronutrient availability* for 5.82%.

After obtaining the CIDI weighting scheme, CIDI scores and ranks were calculated. The CIDI scores are calculated using the official GFSI data and the newly obtained weighting scheme. Table 3 presents the results of our research, giving the CIDI scores, CIDI ranks, as well as their comparison to the official GFSI scores. The results are shown for 20 top ranked countries.

Table 3. CIDI Scores, CIDI Ranks, and Comparison with the Official GFSI Scores and Ranks for 2015; 20 Top Ranked Countries

Country	GFSI Score	GFSI Rank	CIDI Score	CIDI Rank
United States	89.0	1	89.09	1
Singapore	88.2	2	88.80	2
Netherlands	85.0	5	86.80	3
Australia	83.8	9	86.28	4
Ireland	85.4	3	85.80	5
France	83.8	10	85.37	6
Canada	84.2	7	85.17	7
Sweden	82.9	12	85.11	8
Austria	85.1	4	85.03	9
New Zealand	82.8	13	84.64	10
Germany	83.9	8	84.08	11
Denmark	82.6	14	83.97	12
Switzerland	84.4	6	83.59	13
Norway	83.8	11	83.40	14
Portugal	80.5	16	83.27	15
Finland	79.9	17	82.28	16
United Kingdom	81.6	15	81.98	17
Spain	78.9	20	81.36	18
Belgium	79.5	18	80.83	19
Israel	78.9	19	80.20	20

Table 3 shows certain difference between the official GFSI and the CIDI ranks. Namely, US and Singapore remain on top of the list no matter the method applied. In the presented group of countries, Australia advanced the most, for five places, while Switzerland significantly dropped rank from 6th to 13th position. Generally, these countries slightly changed positions after applying the new weighting scheme. The observed change in ranks is due to the new objective weighting scheme which is calculated using the results of the twofold I-distance approach. Taking a look on the results from the perspective of policy makers, interesting conclusions can be made. Namely, the new weighting scheme gives policy makers a new ranking which is free of subjective claims. Therefore, they cannot be instructed to improve certain aspect of food security and neglect the others which might need substantial policy and financing reforms.

5. Uncertainty and sensitivity

5.1. Official GFSI uncertainty and sensitivity

To analyse the newly obtained CIDI weighting scheme, the uncertainty and sensitivity of the GFSI were performed. Their results will act as a benchmark to evaluate the research findings. Namely, comparing the frequency matrices and the sensitivity graphs, one can conclude which of the two approaches provides more stable results.

Table 4. Uncertainty and Sensitivity of GFSI Ranks; 20 Top Ranked Countries

Country	**1-3**	**4-6**	**7-9**	**10-12**	**13-15**	**16-18**	**19-21**
United States	10000						
Singapore	9996	4					
Ireland	9983	17					
Austria	21	9979					
Netherlands		10000					
Switzerland		9301	695	4			
Canada		211	9789				
Germany			7319	2681			
France		335	5823	3842			
Norway			3366	6634			
Australia		153	3008	6839			
New Zealand				6015	3985		
Sweden				3985	6015		
Denmark					10000		
United Kingdom					9854	146	
Portugal					146	9854	
Finland						10000	
Belgium						9870	130
Israel						130	9870
Spain							10000

The uncertainty and sensitivity analysis are based on the relative contribution of the indicators estimated as the proportion of an indicator score multiplied by the respective weight with regard to the overall country score (Dobrota et al., 2015a; 2015b). Monte Carlo simulation was used to simulate the results for 10.000 times. The frequency matrix of the countries' ranks based on the GFSI for the 20 first ranked countries is given in Table 4.

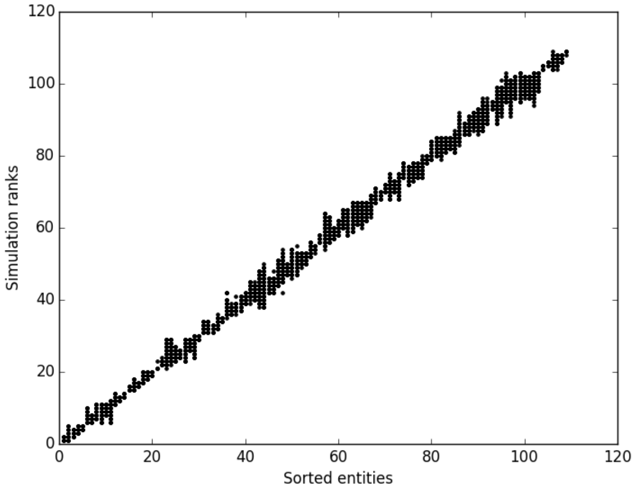

Figure 2. Uncertainty and Sensitivity of GFSI

The United States, Singapore and Ireland are averagely ranked as top 3 countries according to the Monte Carlo simulation of the GSFI ranks. The United States came out as the most stable among the three countries, being ranked in the same range for all 10.000 simulations. Singapore and Ireland have been ranked in positions 1 to 3 for more than 99% of simulations. Besides these countries, only Austria entered the top 3 in just 21 simulated scenarios (0.2%). By moving down the rank, we can see that the results display a certain level of stability. For example, Switzerland, ranked 6th in the overall, found its place from 4th to 12th place. Although it was ranked between 4th and 6th place for 93% of simulated cases, its rank varied. Also, another example of a very uncertain position is Australia. Namely, it could be ranked anywhere between 4th and 12th place, like Switzerland, but in most of the simulations it was ranked between 10th and 12th place, in 68.39% of cases. Looking at the rest of the ranks, the results begin to display a higher level of sensitivity, especially in the middle and the end of the ranking list (Figure 2).

According to these results, we can conclude that counties are medium sensitive to the methodological assumptions in the GFSI. The perceived higher sensitivity in the middle of the ranking is tolerable. According to Saisana and D'Hombres (2008) "highly sensitive" entities are those which do neither have good nor bad results, but they are somewhere in between. The high sensitivity of their ranks is therefore not caused by the methodological assumption of the composite index, but because of their indicator values.

5.2. CIDI uncertainty and sensitivity

Again the same analysis was performed, but now on the CIDI scores and relative contributions. Similarly, the results were simulated 10.000 times using the Monte Carlo simulation. The frequency matrix of the countries' ranks based on the CIDI for the 20 first ranked countries is given in Table 5.

Table 5. Uncertainty and Sensitivity of CIDI Ranks; 20 Top Ranked Countries

Country	1-3	4-6	7-9	10-12	13-15	16-18	19-21
United States	10000						
Singapore	10000						
Netherlands	9705	295					
Australia	295	9705					
Ireland		10000					
France		9446	552	2			
Canada		530	9470				
Sweden		2	9932	66			
Austria		22	9978				
New Zealand			68	9931	1		
Germany				9490	510		
Denmark				9325	675		
Switzerland				522	9371	107	
Norway				153	9829	18	
Portugal				510	9490		
Finland				1	123	9876	
United Kingdom						9999	1
Spain					1	9997	2
Belgium						3	9997
Israel							10000

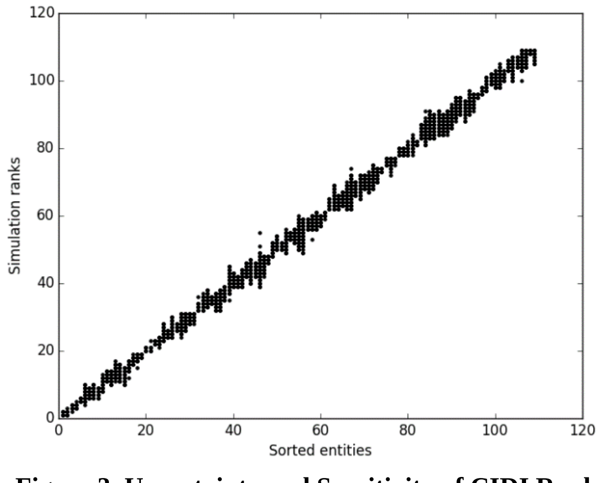

Figure 3. Uncertainty and Sensitivity of CIDI Ranks

Simulation of the CIDI scores marked the United States, Singapore and Netherlands as the top 3 countries. Ireland, ranked third in the GFSI simulation, was replaced by the Netherlands and dropped rank to 5th position. Both United States and Singapore were ranked in the top 3 places in all 10.000 simulations. However, Netherlands was ranked in the same range in 97.05% of simulations, which is less than in the GFSI case, where the third ranked

Ireland was in the same range in 99.83% of the simulated cases. Moving down the ranks, Australia appears as an interesting entity. Namely, it improved its position and ranks 4th by the CIDI simulation, whereas its range is from 1st to 6th place. Its results prove to be more stable, as in the case of GFSI it could have taken any place between 4th and 12th. Switzerland, on the other hand, dropped rank and is now 13th. In 93.71% of cases, it was ranked between 13th and 15th place. We can see the overall stability of the CIDI in Figure 3.

Figure 3 shows a slight elevation of stability in the middle and the end of the ranks. Thus, CIDI proposes a more stable methodology that decreases the entropy of the system (Dobrota et al., 2015a).

6. Discussion and Conclusion

Global climate change, population and income growth, and the economic crisis have all had and will have, directly or indirectly, an impact on the global food situation (Carletto, Zezza & Banerjee, 2013). In such a turbulent time for food and nutrition related issues, food security emerged as an aspect worth observing by scholars, international institutions, and governments. Namely, the development and the ability of agriculture to respond to demands has been a concern on the global policy agenda.

Achieving food security requires careful policy reforms and budget restructuring on mutual levels due to is its multidisciplinary nature (Santeramo, 2015b). Therefore, a need for a food security metric emerged. Even before their creation, food security metrics faced the fact that the subject of measurement has not been universally defined. However, dozens of indicators were proposed in the last half-century, but the question regarding their theoretical basis, universality, and statistical soundness arises (Cafiero et al., 2014). Nevertheless, significant progress towards creating a reliable food security index on a global scale has been made.

Herein we scrutinized the GFSI, a global composite index that measures all three aspects of food security. The aim of the research paper was to reduce the level of subjectivity of its weighting scheme. Inadequate weights might deceive the last end users by giving them questionable results and a distorted image of the measured phenomenon. Therefore, we employed the CIDI methodology that is based on the I-distance method to obtain unbiased weights for both index indicators and categories.

CIDI method proposed significantly more balanced weights on the category level. Such an approach more strictly follows the definitions of food security and takes into account the hierarchical relationship between the three categories. When it comes to indicator weights, some of them drastically changed, especially weights of the category *Availability*. Effective weights of some of its indicators are quite low (for example weights of indicators A2 2.76% and A7 2.91%) meaning the indicators of this category can be revised and reduced.

Directions of the future studies on the topic elaborated could incorporate the application of a hybrid subjective-objective model. Such model undermines the application of the CIDI methodology on just one level of the indicator while the weights on the other level would remain as recommended by the experts. A recently conducted study supports such an approach as it proved that expert opinion should be taken into account when creating or revising a composite indicator (Zhou, Ang, & Zhou, 2010). Applying both objective and subjective weighting methodologies creates a more balanced ranking system, as employing just one weighting methodology might create a rigid measurement. Another direction could be towards reducing the number of index indicators. The obtained CIDI weights, especially in the category *Availability*, show discrepancies, which means there is a place for refinement. I-distance post hoc is one of the possible analyses that could be employed to revise the number of indicators (Markovic et al., 2015). Also, countries can be grouped by the level of economic development and then ranked using the CIDI. The reason behind such an attempt lies in the volatility of the food situation. Namely, in developing countries, the food situation if often unpredictable, so household have other priorities regarding food compared to developed countries (Wolfe & Frongillo, 2001). It would be interesting to see whether there will be changes in the weighting schemes between the two groups, particularly in the category level.

The presented paper has several benefits that should be pointed out. Firstly, it aims at introducing more objective weights into a food security composite index. Secondly, it employs CIDI methodology and the twofold I-distance approach which have been used with success in previous studies (Maricic & Kostic-Stankovic, 2014; Jovanovic-Milenkovic et al., 2015). Thirdly, the newly proposed weighting scheme reduces the entropy of the system, making it more stable, and trustworthy. We believe that the proposed methodology for in-depth analysis of composite indicators employed on the Global Food Security Index can initiate further research on the statistical soundness and robustness of composite indicators of food security.

Appendix

In order to better explain how the I-distance method works, we provide an example. Let's observe a fictive composite index which has three components A, B and C (we present only a small example since the entire procedure would occupy a significant number of pages). According to data, we will choose a new, fictive entity which has the observed minimum values of all five indicators. In our case, the values of the fictive entity are (2.7, 2.3, 1.7). The I-distance is an iterative process because it aims to the increase the explained level of variability with the introduction of each new indicator in the ranking process. Therefore, the first step is to find out which of the three variables is the most important and which encompasses the highest amount of information on the observed phenomenon (Jovanovic-Milenkovic et al., 2015). To acquire such information, the Pearson's correlation coefficient between the three variables was calculated. The variable which correlates the most with the remaining two variables is variable A. The order of the remaining variables is B and C. According to the observed order, the variables are introduced in the ranking procedure. The next step is to calculate the distance for each entity from the fictive entity. To do this, the matrix of partial correlations is needed:

$$R = \begin{bmatrix} 1 & r_{12} & r_{13} \\ r_{12} & 1 & r_{23.1} \\ r_{13} & r_{23.1} & 1 \end{bmatrix}$$

Before we utilize the I-distance formula (1), more explanation of the formula is to follow.

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

$D^2(r,s)$ is the value of the I-distance between the observed entity r (in our case country) and the fictive entity we created s. We calculate the sum of all distances calculated for all observed indicators (subscript k). The I-distance aims to explain more variability with each new variable that enters the process. The variable which first enters the process is the most important as it explains the largest part of variability. Therefore, in the next step, when entering the second variable, the method aims at reducing the part of variability which is explained with both the first and the second variable.

Finally, we calculate the I-distance value for the chosen entity whose indicator values are (3.3, 4.0, 4.2):

$$D^2(r,s) = \frac{(X_{1r} - X_{1s})^2}{\sigma_1^2} + \frac{(X_{2r} - X_{2s})^2}{\sigma_2^2}.(1 - r_{12}^2) + \frac{(X_{3r} - X_{3s})^2}{\sigma_3^2}(1 - r_{13}^2)(1 - r_{23.1}^2)$$

Following the order of the variables, the values of both fictive and chosen entity we calculate the I-distance value.

$$D^2(r,s) = 2.576$$

The previous procedure is performed for each of the observed entities from the dataset. After having obtained the I-distance values of all entities, we have to check the correlation of variables with the I-distance value. If the order of variables by significance with the I-distance is identical as the initial order of variables the method is concluded. If not, a new order of variables is introduced, and the I-distance procedure is repeated. In our case, r_A=0.975, r_B =0.892, and r_C=0.859 meaning that the procedure is concluded.

The presented procedure was firstly performed on the three GFSI categories. In the following step, the I-distance values of each category were imputed in the procedure to obtain the Total I-distance values. Finally, countries could be ranked based on the Total I-distance value and category weights could be devised.

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