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Methodological challenges in building composite indexes: Linking theory to practice¹

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ABSTRACT

Composite indicators are emerging in several fields and disciplines as appealing method to synthesize a multitude of information, in a compact, single, and unique way. The process of aggregating heterogeneous information is itself very challenging and exposed to numerous threats. The chapter deepens on the methodological challenges that scientists, analysts, and final users must be aware of for a correct interpretation of the composite indexes. By mean of a worked example on the construction of composite indicators for food security, the chapter concludes that while different normalization and weighting approaches do not alter composite indicators, data imputation and aggregation methods are the most crucial steps: different methods convey very different results. For instance, the adoption of different aggregation procedures may largely alter the rankings based on composite indicators. In sum, the analysis shows that the index construction decisions matter and comment on policy and practical implications for the construction of composite indicators.

Keywords: Composite Indicator, Food Security, Data Aggregation, Data Imputation, Normalization, Weighting, FAO, Development, Economics

INTRODUCTION

Composite indicators are emerging in several fields and disciplines as appealing method to synthesize a multitude of information, in a compact, single, and unique way (Santeramo et al., 2012; Caracciolo and Santeramo, 2013; Dobrota et al., 2015; Mahadevan and Hoang, 2015; Santeramo, 2015, 2016; Santeramo and Shabnam, 2015; Alam et al., 2016; Maricic et al., 2016). The process of aggregating heterogeneous information is itself very challenging and exposed to numerous threats. The chapter deepens on the methodological challenges that scientists, analysts, and final users must be aware of for a correct interpretation of the composite indexes. The added value of this chapter is it builds on a worked example: the construction of composite indicators for food security. Food security is one of the most debated topic, the main theme of the world EXPO 2015, and the first of the Millennium Goals. Needless to say, there has been much debate on food security (Wheeler and von Braun, 2013; Hertel, 2016). Numerous indicators of food security have been proposed aimig at establishing the level of food security at country level. Such a variey of indicators and the lack of consensus on how to evaluate policies (and outcomes) aimed at reducing food insecurity, have pushed international organizations to adopt composite indexes to synthesize the information. From a practical pont of view, the construction of composite indexes consist of several steps: indeed, each choice is able to influence the composite indicator (Nardo et al., 2005).

The chapter is intended to achieve two goals: first I aim at providing an helicopter view of the process of building composite indicators, from the analyst point of view; second, I provide a practical example of how heterogeneous information are synthesized in a single index and highlight the warnings that should be clear to analysts, policymakers, and audience, when computing, examining or reading results from composite indicators. The chapter is divided in different sections. The methodological section, which follows the present section, presents the steps required to build a composite indicator; the worked example on Food Security puts the theory into practice; the paragraph is followed by a digression on how

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policymakers and the large audience should interpret composite indicators; the final section concludes with suggestions for future research.

In particular, the worked example provides insights on the challenges faced by analysts called to measure food security. The debate is hot as attested by the large number of articles published on this issue, and the large number of indicators on food security (Gabbert and Weikard, 2001; Carletto et al., 2013; Aurino, 2014; Cafiero et al. 2014; Santeramo, 2015a, 2015b; Svedberg, 2011; Carman et al., 2016; Ames et al., 2016). I provide a practical example by computing several composite indexes for food security by using data provided by the Food and Agricultural Organization. I evaluate a set of techniques that are adopted in the construction of composite indicators. In particular I assess the relevance of methods to impute, homogenize, weight and aggregate data in order to compute composite indexes are compared and the relevancy of the choices to be made will be discussed. I conclude that while different normalization and weighting approaches do not alter composite indicators, data imputation and aggregation methods are the most crucial steps: different methods convey very different results. In sum, I show that the index construction decisions matter. The last two sections go beyond the methodology and focus on the implications of my findings for practitioners, policymakers, and audience. In particular, I discuss how we should interpret the result of composite indexes in order to minimize the impact of discretionary choices.

All in all, the chapter guides the reader to understand how theory and practice match (or not) when we synthesize composite/complex information into single indicators.

BACKGROUND AND METHODOLOGY

The process of building a composite indicator is challenged in many ways and in particular previous assessments of strategic objectives have been incorrectly conducted due the use of “*indicators that were not systematically SMART [that is Specific, Measurable, Achievable, Relevant and Time-bound] and were often focusing on outputs and activities*” (FAO, 2013). Moreover, composite indicators are inherently threatened by the low quality of indicators, the infeasibility of desired indicators, the necessity of homogenizing standards and frameworks. The FAO (2013) suggests that the entire process should “*enhance capacities of data users to use information more effectively, and how data are used could even be monitored in order to justify enhancements and to allow for better prioritization. A continuous and joint assessment of data needs as well as of existing available data, is essential in order to identify gaps and agree on actions to address them*”. The above picture clarifies the challenges for the next future. Constructing composite indicators is only the first, yet crucial, step to be achieved to understand the phenomenon under analysis.

The present report summarizes the different phases involved in the realization of a composite index. An excellent reference is provided by Nardo *et al.* (2005). Following the handbook, I divide the process of building a composite indicator in six main points:

- (1) *Defining the phenomenon* – The step consists in defining the theoretical basis for the selection and combination of single indicators into a composite indicator.
- (2) *Selecting variables* – The second step is also very important is that the single indicators need to be picked on the basis of several features: analytical soundness, measurability, country coverage, relevance to the phenomenon being measured and relationship to each other. In addition, when direct data are not available, *ad hoc* proxy variables may be adopted.
- (3) *Filling the gaps* - Consideration should be given to different approaches for imputing missing values. Extreme values should be examined as they can become unintended benchmarks.
- (4) *Homogenizing the information* - Indicators should be normalized to render them comparable.
- (5) *Weighting and aggregating* – Indicators should be aggregated and weighted according to the underlying theoretical framework. Multivariate analysis could be a preliminary or complementary step.
- (6) *Validating the composite indicator* – The validation of the composite indicator is aimed at the assessment of the robustness of the composite indicator. Finally, attempts should be made to correlate the composite indicator with other published indicators as well as to identify linkages through regressions.

The remainder of this chapter deepens on theoretical and empirical issues. The final goal is to present how to build a composite indicator and provide a worked example: the construction of a composite indicator for food security.

RESEARCH CONTEXT

The section aims at detailing the necessary steps to construct a composite indicator. Although not comprehensive, the described methodology should provide the minimum tools to construct a composite

indicator to measure and evaluate a complex phenomenon. The first step “*Defining the phenomenon*” is the starting point of any composite indicators has to be the definition of the phenomenon under investigation and I aim at measuring.

A precise and concise definition of the complex phenomenon is a necessary, although not sufficient, prerequisites for constructing a useful composite index. It is very likely that a badly defined concept will be badly measured, monitored and evaluated, exactly as we would never be able to target a goal we have not clear in mind.

From a more practical perspective, the first step of the analysis consists in defining the concept under investigation (e.g. how do we define food security?), in determining sub-groups, or dimensions (e.g. determinants, outcome, and stability), and finally in identifying the indicators or variables that allow to measure all sub-components (e.g. determinants is measured by indicators of food availability, physical access, and so on).

The second step, “*Selecting variables*”, consists in selecting the variables that will produce the composite indicator. Rely on variables of good quality is a major issue for constructing composite indexes. Ideally, variables should be SMART, that is specific, measurable, accessible, relevant, and timeliness.

The data selection process is somehow subjective: it usually involves a set of heterogeneous indicators, from quantitative (hard) data, to qualitative (soft) data collected from surveys or policy reviews, or to proxies to convey into the index more information on the phenomenon when specific variables are unavailable.

The third step (*Filling the gaps*) consists in filling the gaps in the dataset. The vast majority of dataset are incomplete. When data are missing, it is important to establish if the lack of data is random or systematic: missing data at random depend on the variable itself or on other variables of the dataset (in other terms if that are randomly missing, this is likely to be due to the specific variable it has been adopted); systematic missing data are indeed due to the lack of information on the phenomenon under consideration. Unfortunately, despite the relevance of this distinction there are still no approaches to infer on the nature of the missing data: analysts should therefore adopt the most appropriate techniques to deal with missing data somehow disregarding the nature of the missing.

Common approaches to impute missing data consist in deleting records that contain missing data, in imputing missing data by mean of ad hoc statistics (e.g. mean, median, regression imputation, etc.) or algorithms (e.g. Markov Chain, Monte Carlo algorithm, etc.). None of the approaches is exempt by drawbacks, therefore it is wise to carefully document the selected imputation procedures.

The fourth step is dedicated to “*Homogenizing the information*”. Due to the heterogeneity of measurements units, the indicators in a data set need to be normalized prior to any data aggregation. The analysts may rely on a large set of normalization methods: the choice should be based on the data properties and the objectives of the index it has to be constructed (Freudenberg, 2003; Jacobs *et al.*, 2004).

Normalization methods include, among others, ranking, standardization, min-max, distance to a reference observation, score function, balance of opinions. All in all, normalization methods allow to compare indicators bringing different measurement units on a similar same dimension. Different methods imply different *pros* and *cons*. For instance, ranking method is extremely simple, robust to outliers and allow comparison among observations: a big disadvantage is that the method will eliminate information on levels. Balance of opinions is a different way to go: the method is complex and useful in that missing primary data are imputed through the opinion of experts. As it is easy to imagine, the method is quite costly and of very difficult replication over time and space.

The next step, “*Weighting and aggregating*”, is dedicated to the normalization of the information. The set of selected variables, whose data have been normalized and filled to reduce lack of information, constitute the ingredients of the composite indicator. The final step will be the synthesis of the overall information into few indexes or a unique indicator. In particular, variables have to be properly aggregated and weighted.

As for previous step, a number of weighting techniques exists, none of which is exempt by a discretionary choice (Saaty, 2001). Statistical methods such as unobserved components models, or participatory methods, such as budget allocation, analytic hierarchy processes, and conjoint analysis are available alternatives. The theoretical framework underlying the composite indicator should mentor the selection of the technique. For instance, equal weighting implies that indicators (or dimensions) have similar importance, whereas principal components analysis or factor analysis rely on data variability and variables correlation: both methods allow to synthesize data variability through a reduced number of variables. Needless to say, if variables are not correlated (or low correlated) these methods cannot be applied.

Aggregation is the natural step following the weighting in that it condense the information conveyed by indicators into a single index. Two very common approaches are the linear aggregation and the geometric aggregation. The former, which is feasible when individual indicators have the same measurement unit,

transfers the relative importance of single indicators to the composite index. In other terms, it is a conservative measure. On the contrary, geometric aggregations allows to take into account non compensability between indicators or dimensions.

The last step, “*Validating the composite indicator*”, is aimed to ensuring the external validity of the composite indicator. The described process of constructing a composite indicator, required several judgment calls, in particular those involved in steps 2 - 4, that conflict with the goal of producing a scientific, objective, incontestable indicator of the complex phenomenon. The composite indicator, and the other results (e.g. rankings) should be validated through robustness checks and sensitivity analyses. The most common procedures are uncertainty analysis, focusing on how uncertainty in the input factors propagates through the structure of the composite indicator and affects the composite indicator values, and sensitivity analysis aiming at evaluate the contribution of the individual source of uncertainty to the output variance. Finally, the composite index should be compared to other proposed composite indicators.

DISCUSSION

Ensuring food security is “the challenge of feeding 9 billion people” (Godfray et al., 2010), the first Millennium Development Goal, and one of the most debated topic in Academia and International Organizations. Despite impressive achievements at the global level, with 700 million fewer people living in extreme poverty conditions in 2010 than in 1990, the United Nations estimates that 1.2 billion people are still living in extreme poverty. It is also true that governments are making every effort to eradicate hunger, poverty, and undernourishment, and policy interventions shooting for these targets are under the spotlight. On their side, the International Organizations, such as FAO or WB, reward governments successfully progressing in fighting food insecurity, and provide guidelines to policymakers. Thus, while Chile, China and Morocco have won recognition from FAO, on June the 16th 2014, for their outstanding progresses to reach elevate food security standards, scholars are animatedly debating on how to measure (and improve) food security status.

The most widely adopted definition of food security is ‘*a situation that exists when all people, at all time, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*’ (FAO, 2013).

However, how the definition can be translated into an actual measure of the level of food security is still debated. It has to be recognized that the existing indicators are not equivalent, indeed they convey different information on food security (Barrett, 2010). Further complexity arises when indicators are *complex*. Data quality, double counting, data aggregation are just few of the issues that researches need to deal with when computing food security composite indexes. For instance, while existing indicators such as the Global Food Security Index, the Global Hunger Index, and the Poverty and Hunger Index, are already in use, there is no consensus on which methodology should be adopted to build food security composite indicators.

Based on the procedure described in previous sections, I present how to compute a composite indicator for food security: the variables used in the present analysis have been collected on FAOSTAT website.

The dataset FAO - FOOD SECURITY INDICATORS (released on October 9, 2012 and revised on March 15, 2013) is constructed by following the recommendation of experts gathered in the Committee on World Food Security (CFS) Round Table on hunger measurement, hosted at FAO headquarters in September 2011. In particular, I use all indicators provided by the FAO that have sufficient coverage to enable comparisons over time and space (Cafiero, 2013), and suggested as indicators of food security. The FAO has been recently expanded to introduce several new indicators to fill lack of information. I aim at introducing this new information to build a new index for food security.

Variables have been sub-divided in groups: the first group consists of indicators of the determinants of food insecurity (structural conditions that are likely to worsen food insecurity in the absence of adequate policy interventions); the second group merges variables on outcomes of food insecurity (e.g. inadequate food consumption or anthropometric failures); the third group provides information on the vulnerability to food insecurity (e.g. past variability of outcomes and conditions conducive to vulnerability to shocks). Within the first two groups, the indicators are further classified based on the dimension of food insecurity on which they provide information. The first group is split in variables capturing availability (Average Dietary Energy Supply Adequacy; Average Value of Food Production; Share of dietary energy supply derived from cereals, roots and tubers; Average protein supply; Average supply of protein of animal origin), physical access (Percent of paved roads over total roads; Rail-lines density; Road density), economic access or affordability (Domestic Food Price Level Index), and utilization (Access to improved water sources; Access to improved sanitation facilities). The second group includes variables on Inadequate access to food (Prevalence of

undernourishment; Share of food expenditure of the poor; Depth of the food deficit; Prevalence of food inadequacy), and Utilization (Percentage of children under 5 years of age who are stunted; Percentage of children under 5 years of age affected by wasting; Percentage of children under 5 years of age who are underweight; Percent of adults who are underweight). The third group, “Vulnerability/stability” includes “Domestic food price level index volatility”, “Per Capita food production variability”, “Per Capita food supply variability”, “Political stability and absence of violence/terrorism”, “Value of food imports over total merchandise exports”, “Percent of arable land equipped for irrigation”, “Cereal import dependency ratio”. The composite indicator reflects the above described theoretical framework.

A variety of indicators for food security have been proposed. However, it is still unclear if “*these different constructs equally represent the different domains of food security*” (Jones *et al.*, 2013). Moreover, I believe any of such indicators are sufficient to measure and monitor the state of food security, in that “monitoring of food security should be [further] complemented by anthropometric measurements” (Pinstrup-Andersen, 2009).

I have identified four crucial “choice nodes” (Table 1): data filling, data transformation, weighting, and aggregation. The data filling (or data imputation) is the process of replacing missing data with substituted values. The data transformation consists in the rescaling of data to a unique scale. The weighting and aggregation procedure are steps that allows to move from multiple indicators to a unique indicator (aggregation) attributing different relevance (weighting) to the single indicators.

In particular, I test for two methods to deal with missing data (multiple imputation and simple imputation), two methods to normalize data (by mean of z-score and by mean of the normalization adopted by intelligence unit to compute the Global Food Security Index 2013ⁱ, namely the Min-Max method), four approaches to weight sub-indexes (Equal weighting, empirical rank correlation, inverse correlation, and correlation by a shrinkage estimation), and three alternatives to aggregate information (linear aggregation, simple geometric aggregation, and CES aggregationⁱⁱ).

The variety of alternatives analyzed and compared provides, to the best of my knowledge, the first systematic attempt to assess (quantitatively) results from different indexes.

I compare eight different composite indicators, the baseline composite indicator and seven other composite indicators that differ from the baseline only for one method in one of the four “choice nodes”. Although the set of potential alternatives is very large, I have focused on the alternatives proposed in other studies (*cfr.* Nardo *et al.*, 2005a, 2005b). The baseline scenario has been obtained by adopting methods that are commonly adopted for composite indicators (Nardo *et al.*, 2005a): multiple Imputation, normalization through z-score, equal weighting and linear aggregation. It is worth note that most of the proposed indexes such as the Global Food Security Index and the Global Hunger Index are a slight variant of the baseline scenario. Each indicators have been normalized to a 0-100 score to make them directly comparable with other indicators.

Table 1. Different approaches for food security composite indicator

<i>Scenarios</i>	<i>Imputation</i>	<i>Normalization</i>	<i>Weighting</i>	<i>Aggregation</i>
1 - Baseline	<i>Multiple</i>	<i>Z-score</i>	<i>Equal</i>	<i>Linear</i>
2	<i>Multiple</i>	<i>Z-score</i>	<i>Rank correlation</i>	<i>Linear</i>
3	<i>Multiple</i>	<i>Z-score</i>	<i>Inverse correlation</i>	<i>Linear</i>
4	<i>Multiple</i>	<i>Z-score</i>	<i>Shrinkage</i>	<i>Linear</i>
5	<i>Multiple</i>	<i>Normalization</i>	<i>Equal</i>	<i>Linear</i>
6	<i>Multiple</i>	<i>Z-score</i>	<i>Equal</i>	<i>Geometric</i>
7	<i>Multiple</i>	<i>Z-score</i>	<i>Equal</i>	<i>CES</i>
8	<i>Simple</i>	<i>Z-score</i>	<i>Equal</i>	<i>Linear</i>

Supposing a two variables (x_1 and x_2) composite indicator, a linear aggregation would be $x_1 + x_2$, a geometric aggregation would be $(x_1 * x_2)^{(1/2)}$ and a CES aggregation would be $(x_1^y + x_2^y)^{(1/y)}$.

I compare the methods in terms of absolute deviations of ranking from the baseline scenario. The larger the deviation of ranking from the baseline scenario, the larger the distortion implied by the method for which the scenario under consideration differ from the baseline. It is worth emphasizing that the scenarios differ from the baseline only for one method. I apply the formula

SOLUTIONS AND RECOMMENDATIONS

I adopted different methodologies at four “choice nodes”: filling missing data, homogenizing the information, weighting information and aggregating information. I compared changes in rankings obtained by eight different composite indexes. The larger the differences in rankings induced by selecting alternative methods, the larger the importance of the choice, the wiser the decision-making process should be.

Choice of the methods to compute composite indexes have different relevance: decisions on normalization and weighting methods are not very relevant; conversely, different techniques for data imputation seem to convey very heterogeneous outcomes. Lastly, the aggregation formula that is adopted is able to influence the entire composite indicator: different formulas provide very different composite indexes. What this really imply for practitioners and policymakers?

Let me clarify with an emblematic examples may help the reader flavoring the relevance of choices. According to the baseline Index, Congo and Tanzania rank, respectively, 214 and 196 out of 228: their population (respectively 4 and 45 millions) are *food insecure*. However, if a different choice on the aggregation procedure would have been made, for instance if a geometric aggregation would have been adopted, these Countries would have been ranked 88th and 166th. Not only their overall rank would have been improved, but they would have also been reversed, implying that Tanzania would have been considered more food insecure than Congo!

The practical and policy implications are very important: the construction of composite indicators may substantially alter the rankings for food security. Is this opening the path of strategic behavior? Would different governments prefer different indicators? Let me reply withan emblematic examples. Let 's consider Chile, China and Morocco. According to my results, each of these Country would prefer a different way to climb the ranking: Chile would be better off in the ranking if simple imputation, or inverse correlation would have been adopted; China would gain 7 positions in the world rank if I would have simply used a different normalization techniques; Morocco may have been better off if a different aggregation method would have been chosen. This poses the basis for a strategic behavior: governments are likely to target to be highly ranked depending on the specific composite indicator adopted by the International Organization. This is very far from the motivating aim for constructing a composite indicator. We may have left in the scientists and analysts' hands too flexible tools (and too many degrees of freedom): the current situation call for future research on how to build composite indicators for food security.

SUGGESTIONS FOR FUTURE RESEARCH AND CONCLUSION

Composite indicators have started to be applied in several contexts as holistic tool to measure complex phenomenon. While increasing in number and prominence, they still lack of solid theoretical and methodological foundations. Nardo (2005) provides an excellent review of the methods embedded in the construction of composite indexes, and pinpoints strengths and weaknesses of different techniques. Moving from the theory to the practice is a big jump, therefore analysts and final users, need to be aware of the practical implications that different choices may imply. In order to explore the methodological challenge to build composite indicators, with a fresher perspective, I have analyzed a practical example: the construction of a food security composite indicator.

The debate on food security is rapidly growing (Ouertani, 2016; Santeramo, 2015, 2016), and it concerns a wide range of disciplines. A large set of indicators have been proposed. However, measuring the phenomenon as a whole is *per se* important and therefore how different single indicators should be aggregated is very important. I emphasize how relevant may be the analyst's choice of algorithms to compute composite indicators by comparing different techniques to build composite indexes of food security. Different methods have different impacts on rankings: normalization and weighting are (relatively) less crucial decisions, whereas special attention has to be paid in choosing the data imputation and aggregation methods.

Needless to say, the research presented here is not exempt from limitations. In particular, the results cannot be generalized to other composite indicators. Different theoretical framework and different data may lead to diverse sensitiveness of their composite indicator to alternative methods. However, the validity of the present

research is to highlight the importance of testing the robustness of the ranking obtained through composite indicators. A second limitation consists in the reduced number of alternatives (for each step in the construction of the composite indicator) I have analyzed. Indeed this represents a suggestion for future research.

Despite the limitations stated, the implications of the present study are very relevant as I showed that simply modifying the adopted data imputation technique or the aggregation method alter the rankings, and thus suggest to the governments of the therefore named “food insecure” Countries to take measures. The provocative question I raise is: to what extent analysts are able to synthesize a complex phenomenon such food security by mean of a single composite indicator? And how governments should interpret the message that existing food security indicators convey?

I suggest that, when proposing new composite indexes, the United Nations, the international agencies, academics and researchers, should pay careful attention to emphasizing how they jumped from raw data into a single index. Without a clear and transparent procedure, no judgment or comparison with existing indicators can be made. As my simplified example shows, the political and practical implications of each choice are very relevant.

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KEY TERMS AND DEFINITIONS

Aggregation: Process of synthesizing single variables and indexes into a multidimensional indexes.

Composite index: A combination of simple variables or indexes to measure a complex phenomenon.

FAO: The Food and Agriculture Organization of the United Nations is an agency leading international efforts to eradicate hunger and ensure food security.

Food Security: The condition existing of having access to adequate and safe food.

Imputation: Process of replacing missing data through different techniques.

Millennium Goals: World targets to reduce global poverty by the first two decades of 2000s

Validation: Process of demonstrating that the model is a reasonable representation of the phenomenon under consideration

i The report is available at: <http://foodsecurityindex.eiu.com/>

ii Geometric aggregation is intended to capture the hierarchical structure of the phenomenon. As Barrett (2010) pointed out, “availability, access, and utilization [...] are inherently hierarchical, with availability necessary but not sufficient to ensure access, which is, in turn, necessary but not sufficient for effective utilization”. The structure calls for further research on how to aggregate sub-index. An alternative, yet not empirically investigated, is to use a quasi-linear aggregation method, or to use a *Stone-Geary-type* function.