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Measuring Well-Being Over Time: The Adjusted Mazziotta–Pareto Index Versus Other Non-compensatory Indices

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Abstract Most of the socio-economic phenomena such as development, well-being, and quality of life have a multidimensional nature and require the definition of a set of individual indicators to be properly assessed. Often, individual indicators are summarized and a composite index is created. One of the main problems in constructing composite indices is the choice of a method which allows time comparisons. In this paper, we consider the Adjusted Mazziotta–Pareto Index, a non-compensatory composite index used by the Italian National Institute of Statistics for measuring "Equitable and Sustainable Well-being" in Italy. An empirical comparison with some traditional non-compensatory indices is presented and an Influence Analysis is, for the first time, performed in order to assess the robustness of the index.

Keywords Multidimensional data analysis · Composite index · Ranking Non-compensability

1 Introduction

In the recent years, many have been the attempts of different institutions (universities, statistics offices, international organizations) to construct composite indices of development, well-being, or quality of life. The results are used to either create a country ranking or to simply summarize the data (Booysen 2002; Bandura 2008).

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Important examples are the United Nations' Human Development Index—HDI (UNDP 2001, 2010), the Waterloo University's Canadian Index of Wellbeing—CIW (Michalos et al. 2011), and the Economist Intelligence Unit's Quality of Life index.[1]

In Italy, since 2010, the National Institute of Statistics (Istat) and the National Council for Economy and Labour (Cnel) have launched a project, called "Equitable and Sustainable Well-being" (BES), for constructing a set of measures of the various dimensions of well-being, at the regional level. The third edition of the "Report on Equitable and Sustainable Wellbeing" (Istat 2015) contains, for the first time, a composite measure for each dimension of well-being obtained by applying the Adjusted Mazziotta–Pareto Index (AMPI). The same method was used by the Mexican Institute of Statistics and Geography (INEGI) for measuring Well-being in the Mexican States (OECD 2015).

The AMPI is a non-compensatory (or partially compensatory) composite index that allows comparability of the data across units and over time (Mazziotta and Pareto 2016). It is a variant of the Mazziotta–Pareto Index (MPI), based on a re-scaling of the individual indicators by a Min–Max transformation, in contrast with the classic MPI where all the indicators are normalized by a linear combination of z-scores (De Muro et al. 2011).

In this paper, we consider the AMPI and we empirically compare it with other non-compensatory aggregation methods.

2 Issues in Composite Index Construction

A composite index is a mathematical combination (or aggregation as it is termed) of a set of individual indicators (or variables) that represent the different components of a multidimensional phenomenon to be measured (e.g., development, well-being or quality of life). Therefore, the composite indices are used for measuring concepts that cannot be captured by a single indicator.

Ideally, a composite index should be based on a theoretical framework which allows individual indicators to be selected, combined and weighted in a manner which reflects the dimensions or structure of the phenomenon being measured. However, its construction is not straightforward and often requires a number of decisions/choices (methodological or not) to be taken (Freudenberg 2003). In particular, the main steps for constructing a composite index are the following (Salzman 2003; OECD 2008; Mazziotta and Pareto 2013): (1) Defining the phenomenon to be measured; (2) Selecting a group of individual indicators; (3) Normalizing the individual indicators; (4) Aggregating the normalized indicators; (5) Validating the composite index. Aggregation step has always been an interesting but controversial topic in composite index construction (Saltelli 2007).

A fundamental issue concerning the aggregation is the degree of compensability or substitutability of the individual indicators. The components of a composite index are called 'substitutable' if a deficit in one component may be compensated by a surplus in another (e.g., a low value of "Average water use per person" can be offset by a high value of "Bottled water consumption per capita" and vice versa). Similarly, the components of a composite index are called 'non-substitutable' if a compensation among them is not allowed (e.g., a low value of "Hospital beds per 1000 inhabitants" cannot be offset by a high value of "Medical doctors per 1000 inhabitants" and vice versa). Thus we can define

[1] http://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf.

an aggregation approach as compensatory or non-compensatory[2] depending on whether it permits compensability or not (Casadio Tarabusi and Guarini 2013). Compensability is closely related with the concept of unbalance, i.e., a disequilibrium among the indicators that are used to build the composite index. In a non-compensatory approach, all the dimensions of the phenomenon must be balanced and an aggregation function that takes unbalance into account, in terms of penalization, is often used (unbalance-adjusted function). A compensatory approach involves the use of linear functions, such as the arithmetic mean that ignores unbalances. A non-compensatory (or partially compensatory) approach generally requires unbalance-adjusted functions, such as the AMPI.

Another important issue concerning composite index construction is the level of comparability of the data across units (e.g., countries) and over time (e.g., years). Comparisons over time may be absolute or relative (Mazziotta and Pareto 2013). We say that a time comparison is 'relative' when the composite index values, at time t, depend on one or more endogenous parameters (e.g., mean and variance of the individual indicators at time t). Similarly, we say that a time comparison is 'absolute' when the composite index values, at time t, depend on one or more exogenous parameters (e.g., minimum and maximum of the individual indicators fixed by the researcher). Comparability of the values of a composite index firstly depends on the normalization method. *Ranking* and *standardization* (z-scores) allow only for relative comparisons since they are exclusively based on values of the individual indicators at the time of reference. Other methods, such as *re-scaling* (Min–Max transformation) or *distance to a reference* (index number), require that the minimum and maximum (e.g., the 'goalposts' of the HDI) or the benchmark are independent from the time of reference in order to perform comparisons in absolute terms (Tarantola 2008).

3 The Adjusted Mazziotta–Pareto index (AMPI)

The AMPI is a composite index for summarizing a set of indicators that are assumed to be non-substitutable, i.e., all components must be balanced[3] (Mazziotta and Pareto 2016). It is based on a non-linear function which, starting from the arithmetic mean, introduces a penalty for the units with unbalanced values of the indicators. Individual indicators are normalized by a re-scaling according to two 'goalposts', i.e., a minimum and a maximum value which represent the possible range of each variable for all time periods and for all units. Such type of normalization allows to perform absolute comparisons over time.

The steps for computing AMPI are given below.

3.1 Normalization

Given the matrix $\mathbf{X} = \{x_{ij}\}$, we calculate the normalized matrix $\mathbf{R} = \{r_{ij}\}$ as follow:

$$r_{ij} = \frac{(x_{ij} - \text{Min}_{x_j})}{(\text{Max}_{x_j} - \text{Min}_{x_j})} 60 + 70 \tag{1}$$

[2] Note that we call 'non-compensatory' a not fully compensatory approach. With partial compensability, only small (less than a given amount) decreases in one component may be compensated by suitable increases of the other components (Bramanti and Tarantola 2012).

[3] To overcome the assumption of full substitutability among indicators, some authors propose multiplicative aggregation methods, such as the geometric mean (OECD 2008; Zhou et al. 2010). However, the value of the geometric mean is 'biased' low. Thus it may be useful for measuring phenomena like development (e.g., the HDI), but not like poverty.

where Min_{x_j} and Max_{x_j} are the 'goalposts' for the indicator j. If the indicator j has negative 'polarity',[4] the complement of (1) with respect to 200 is calculated.

To facilitate the interpretation of results, the 'goalposts' can be fixed so that 100 represents a reference value (e.g., the average in a given year). A simple procedure for setting the 'goalposts' is the following.

Let Inf_{x_j} and Sup_{x_j} be the overall minimum and maximum of the indicator j across all units and all time periods considered. Denoting with Ref_{x_j} the reference value for the indicator j, the 'goalposts' are defined as:

$$\begin{cases} \text{Min}_{x_j} = \text{Ref}_{x_j} - \Delta \\ \text{Max}_{x_j} = \text{Ref}_{x_j} + \Delta \end{cases}$$

where $\Delta = (\text{Sup}_{x_j} - \text{Inf}_{x_j})/2$. The normalized values will fall approximately in the range (70; 130), where 100 represents the reference value.

3.2 Aggregation

Denoting with M_{r_i} and S_{r_i}, respectively, the mean and standard deviation of the normalized values of the unit i, the generalized form[5] of AMPI is given by:

$$\text{AMPI}_i^{+/-} = \text{M}_{r_i} \pm \text{S}_{r_i}\text{cv}_i \tag{2}$$

where $\text{cv}_i = \text{S}_{r_i}/\text{M}_{r_i}$ is the coefficient of variation for the unit i.

If the composite index is 'positive', i.e., increasing values of the index correspond to positive variations of the phenomenon (e.g., socio-economic development), then AMPI^- is used. On the contrary, if the composite index is 'negative', i.e., increasing values of the index correspond to negative variations of the phenomenon (e.g., poverty), then AMPI^+ is used. In any cases, a unbalance among indicators will have a negative effect on the value of the index.

Therefore, the AMPI decomposes the score of each unit in two parts: mean level (M_{r_i}) and penalty ($\text{S}_{r_i}\text{cv}_i$). The penalty is a function of the indicators' variability in relation to the mean value ('horizontal variability') and it is used to penalize the units. The aim is to reward the units that, mean being equal, have a greater balance among the indicators values.

The AMPI has the same properties than the MPI. Nevertheless, the AMPI allows to compute the score of each unit independently of the others, in contrast to the MPI where the mean and standard deviation of the individual indicators are requested. The 'price' to pay for having scores comparable over time is that indicators with different variability are aggregated. However, normalized indicators in an identical range have much more similar variability than original ones (Mazziotta and Pareto 2016).

[4] The 'polarity' of an indicator is the sign of the relation between the indicator and the phenomenon to be measured (+ if the indicator represents a dimension considered positive and − otherwise).

[5] It is a generalized form since it includes 'two indices in one'.

4 A Comparison with Traditional Methods

In this Section, an application to indicators of well-being for OECD countries, in 2014, is presented in order to compare the AMPI with some non-compensatory aggregation methods.

Four basic dimensions of well-being are considered (Health, Education, Jobs, Income) and individual indicators are the following:

X_1 = Life expectancy (years);
X_2 = Educational attainment[6] (% of people, aged 15–64);
X_3 = Employment rate (% of people, aged 15–64);
X_4 = Household disposable income (USD − PPPs adjusted).

Note that all the individual indicators have positive polarity, i.e., the greater the value, the higher the well-being. Because the composite index is 'positive', the $AMPI^-$ is used and the 'goalposts' are fixed so that 100 represents the average in 2014.

In order to assess the performance of the AMPI, we compared it with the following aggregation methods:

- Minimum of re-scaled values in [0, 1] (Min),
- Jevons Index with base average 2014 (Jevons).

The first method is fully non-compensatory, because it uses the minimum value of the normalized indicators so that the other values cannot increase the value of the index. This function realizes the maximum penalization for unbalanced values of the indicators (Casadio Tarabusi and Guarini 2013). The second is partially compensatory, as it is based on the geometric mean of index numbers (OECD 2008).[7]

Table 1 shows the data matrix X and the composite indices (values and ranks).

Overall, the results are concordant. A comparison of final rankings by different aggregation methods is presented in Table 2. The Spearman rank correlation coefficient between AMPI and Jevons is $\rho = 0.962$ (mean absolute difference of rank $\Delta = 1.67$, i.e., the rank of each unit changes, on average, of 1.67 positions between the two methods); whereas Min is less similar to both Jevons, with $\rho = 0.945$ ($\Delta = 2.10$) and AMPI, with $\rho = 0.947$ ($\Delta = 1.97$). Indeed, the penalization for unbalanced values of Min is greater than the other methods.

Finally, an Influence Analysis[8] is performed to assess the robustness of the composite indices when excluding an individual indicator. In particular, for each method (Min, Jevons, AMPI) and for each country (Australia, Austria, …, United States), the composite index is computed, by excluding each time a different indicator (X_1, X_2, X_3, X_4). The absolute differences of rank (shifts) between the new rank and the original one are reported in Table 3. Hence, the average shift in countries' ranks, for each indicator removed, is obtained and the main characteristics of these distributions (Fig. 1), such as mean, standard deviation and range, are evaluated.

[6] Educational attainment is measured as the percentage of the adult population (15–64 years of age) holding at least an upper secondary degree, as defined by the OECD-ISCED classification.

[7] Note that only normalization methods to perform time comparisons in absolute terms are considered (*re-scaling* and *distance to a reference*).

[8] Influence Analysis is a particular case of Uncertainty Analysis (Saisana et al. 2005) that aims to empirically quantify the 'weight' of each individual indicator in the calculation of the composite index.

Table 1 Individual indicators and composite indices of well-being. *Source* www.oecdbetterlifeindex.org

Country	Individual indicators				Min		Jevons		AMPI	
	X_1	X_2	X_3	X_4	Value	Rank	Value	Rank	Value	Rank
Australia	82.0	74.0	72.0	31,197	0.672	2.0	108.96	9.0	109.43	8.0
Austria	81.1	82.0	73.0	29,256	0.615	6.0	110.09	7.0	109.73	7.0
Belgium	80.5	71.0	62.0	27,811	0.393	15.0	100.48	15.0	98.69	16.0
Canada	81.0	89.0	72.0	30,212	0.651	5.0	112.85	4.0	111.40	5.0
Chile	78.3	72.0	62.0	13,762	0.034	27.0	83.98	28.0	87.17	25.0
Czech Rep.	78.0	92.0	67.0	17,262	0.165	22.0	96.25	18.0	95.25	20.0
Denmark	79.9	77.0	73.0	25,172	0.462	13.0	103.99	12.0	103.77	13.0
Estonia	76.3	89.0	67.0	14,382	0.057	26.0	90.70	24.0	88.62	23.0
Finland	80.6	84.0	70.0	26,904	0.527	8.0	107.16	10.0	106.51	10.0
France	82.2	72.0	64.0	29,322	0.464	12.0	103.53	14.0	103.59	14.0
Germany	80.8	86.0	73.0	30,721	0.670	4.0	112.67	5.0	111.01	6.0
Greece	80.8	67.0	51.0	19,095	0.000	28.0	85.93	27.0	85.83	27.0
Hungary	75.0	82.0	57.0	15,240	0.071	25.0	86.22	26.0	79.77	29.0
Ireland	80.6	73.0	59.0	23,721	0.286	17.0	96.06	19.0	95.45	19.0
Italy	82.7	56.0	58.0	24,724	0.250	19.0	91.04	23.0	92.66	21.0
Japan	82.7	93.0	71.0	25,066	0.458	14.0	109.08	8.0	111.77	4.0
Korea	81.1	81.0	64.0	18,035	0.194	20.0	94.10	20.0	97.81	18.0
Mexico	74.4	36.0	61.0	12,850	0.000	28.0	68.26	30.0	68.11	30.0
Netherlands	81.3	72.0	75.0	25,697	0.482	11.0	103.93	13.0	106.04	11.0
New Zealand	81.2	74.0	72.0	21,773	0.334	16.0	99.35	16.0	102.75	15.0
Norway	81.4	82.0	76.0	32,093	0.721	1.0	113.91	3.0	113.24	2.0
Poland	76.9	89.0	60.0	16,234	0.127	24.0	91.12	22.0	87.79	24.0
Portugal	80.8	35.0	62.0	18,806	0.000	28.0	76.42	29.0	81.78	28.0
Slovak Rep.	76.1	91.0	60.0	17,228	0.164	23.0	92.76	21.0	86.72	26.0
Slovenia	80.1	84.0	64.0	19,692	0.256	18.0	96.77	17.0	97.97	17.0
Spain	82.4	54.0	56.0	22,799	0.179	21.0	87.55	25.0	89.28	22.0
Sweden	81.9	87.0	74.0	27,546	0.551	7.0	110.71	6.0	112.07	3.0
Switzerland	82.8	86.0	79.0	30,745	0.671	3.0	115.65	2.0	117.64	1.0
U.K.	81.1	77.0	71.0	25,828	0.486	10.0	104.32	11.0	105.44	12.0
United States	78.7	89.0	67.0	39,531	0.512	9.0	117.69	1.0	107.36	9.0
Average	80.1	76.5	66.4	23,757	0.409		100.00		100.00	

As we can see in Table 4, Min (SD = 1.18; range = 3.07) and Jevons (SD = 1.12; range = 2.80) are the most sensitive composite indices. This is due to the fact that the Minimum is not a function that 'summarizes' all the values, whereas the Jevons index is based on a normalization (*indicization*) which gives implicitly weights related to the variability, and then some indicators are very influential (X_2 and X_4) and others have little weight (X_1).[9] For example, considering Jevons for Estonia, Table 3 shows a shift of 13 positions when X_4 is removed and a shift of 1 position when X_1 is removed. Furthermore,

[9] Note that X_1 (Life expectancy) has the lowest coefficient of variation.

Table 2 Comparison of rankings by different composite indices

Composite index	Min	Jevons	AMPI
Rank correlation			
Min	1.000	0.945	0.947
Jevons	0.945	1.000	0.962
AMPI	0.947	0.962	1.000
Mean absolute difference of rank			
Min	0.00	2.10	1.97
Jevons	2.10	0.00	1.67
AMPI	1.97	1.67	0.00

Table 3 Influence analysis. Absolute difference of rank when excluding an indicator

Country	Min				Jevons				AMPI			
	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4
Australia	0.0	0.0	0.0	8.0	1.0	5.0	0.0	6.0	1.0	5.0	0.0	0.0
Austria	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0
Belgium	0.0	0.0	7.0	4.0	0.0	0.0	2.0	7.0	1.0	0.0	2.0	3.0
Canada	0.0	0.0	0.0	1.0	0.0	2.0	1.0	0.0	0.0	2.0	2.0	0.0
Chile	0.0	1.0	1.0	8.0	0.0	0.0	0.0	4.0	0.0	1.0	1.0	3.0
Czech Rep.	0.0	1.0	1.0	4.0	1.0	5.0	1.0	10.0	4.0	3.0	3.0	2.0
Denmark	0.0	0.0	1.0	1.0	1.0	2.0	2.0	0.0	2.0	1.0	2.0	0.0
Estonia	0.0	1.0	1.0	2.0	1.0	3.0	2.0	13.0	4.0	3.0	4.0	2.0
Finland	1.0	0.0	2.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0	1.0	0.0
France	0.0	0.0	6.0	3.0	0.0	4.0	3.0	7.0	1.0	3.0	4.0	1.0
Germany	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	2.0	1.0	0.0	0.0
Greece	0.0	1.0	7.0	0.0	0.0	3.0	3.0	1.0	1.0	2.0	6.0	0.0
Hungary	0.0	1.0	1.0	2.0	1.0	3.0	1.0	3.0	5.0	0.0	1.0	1.0
Ireland	0.0	0.0	1.0	5.0	0.0	1.0	3.0	6.0	3.0	0.0	2.0	1.0
Italy	0.0	0.0	2.0	4.0	1.0	6.0	1.0	4.0	5.0	4.0	1.0	3.0
Japan	0.0	0.0	1.0	7.0	1.0	5.0	0.0	6.0	4.0	5.0	2.0	2.0
Korea	0.0	1.0	2.0	5.0	1.0	2.0	1.0	2.0	2.0	0.0	1.0	4.0
Mexico	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	0.0	0.0	2.0	2.0	0.0	4.0	2.0	1.0	1.0	3.0	2.0	2.0
New Zealand	0.0	0.0	2.0	6.0	0.0	0.0	2.0	0.0	1.0	0.0	1.0	3.0
Norway	0.0	0.0	0.0	2.0	0.0	0.0	1.0	2.0	1.0	0.0	2.0	2.0
Poland	0.0	1.0	1.0	3.0	0.0	4.0	1.0	2.0	1.0	3.0	0.0	1.0
Portugal	0.0	8.0	1.0	0.0	0.0	8.0	0.0	0.0	1.0	6.0	1.0	1.0
Slovak Rep.	0.0	1.0	1.0	2.0	1.0	4.0	1.0	2.0	5.0	2.0	1.0	1.0
Slovenia	0.0	0.0	2.0	3.0	1.0	3.0	0.0	0.0	1.0	3.0	1.0	1.0
Spain	0.0	1.0	2.0	5.0	1.0	6.0	0.0	3.0	5.0	1.0	0.0	4.0
Sweden	1.0	0.0	2.0	5.0	0.0	2.0	0.0	3.0	3.0	1.0	2.0	0.0
Switzerland	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
U.K.	0.0	0.0	2.0	3.0	1.0	1.0	1.0	2.0	1.0	2.0	0.0	1.0

Table 3 continued

Country	Min				Jevons				AMPI			
	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4
United States	2.0	0.0	2.0	5.0	0.0	0.0	0.0	9.0	7.0	4.0	2.0	8.0
Mean	0.13	0.60	1.73	3.20	0.40	2.47	0.93	3.20	2.07	1.93	1.53	1.53

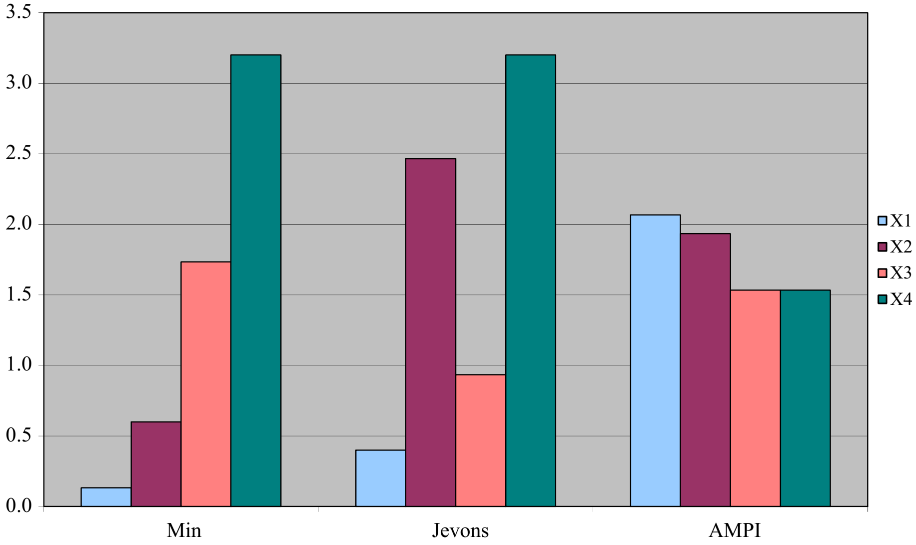

Fig. 1 Average shift in countries' ranks when excluding an indicator

Table 4 Influence analysis. Average shift in countries' ranks when excluding an indicator

Individual indicator	Min	Jevons	AMPI
X_1	0.13	0.40	2.07
X_2	0.60	2.47	1.93
X_3	1.73	0.93	1.53
X_4	3.20	3.20	1.53
Mean	1.42	1.75	1.77
SD	1.18	1.13	0.24
Range	3.07	2.80	0.53

when X_1 is removed with Min, only three Countries change rank (Finland, Sweden and United States).

In contrast to Min and Jevons, in a not fully compensatory approach, the AMPI tends to assign equal weight or importance to each indicator and it is less sensitive to the inclusion or exclusion of individual indicators (SD = 0.24; range = 0.53).

5 Conclusions

Measuring socio-economic phenomena such as development, well-being, and quality of life has become, especially for Statistical Offices, a central topic from a point of view of overcoming the GDP as the 'perfect welfare indicator'. The multidimensional nature of these phenomena requires the definition of intermediate objectives whose achievement can be observed and measured by individual indicators.

The mathematical combination of a set of indicators that represent the different dimensions of a phenomenon to be measured is called *composite indicator* or *composite index*. As is known, building a composite index is a delicate task and full of pitfalls. Its phases involve several alternatives and possibilities that affect the quality and reliability of the results. The main problems, in this approach, concern the choice of a theoretical framework, the availability of the data (in space and over time), the selection of the more representative indicators and their treatment in order to compare and aggregate them. These issues are much more difficult to solve, when the official statistics must 'treat' them.

No universal method exists for composite indices construction. In each case their construction is much determined by the particular application, including formal elements and incorporates some expert knowledge on the phenomenon. Nevertheless, the advantages of composite indices are clear, and they can be summarized in unidimensional measurement of the phenomenon, easy interpretation with respect to a battery of many individual indicators and simplification of the data analysis. The best composite index is the one that respects the objectives required by the researcher or the commitment.

In the case of well-being measurement, the official statistics need to respect some constrains that are essential conditions for a successful measure understandable for an audience not accustomed to technicalities: space-time comparisons, non-substitutability (or partial substitutability) of the individual indicators, simplicity of calculation and transparency, immediate use and easy interpretation of the results, robustness of the method.

The AMPI—adopted by Istat for measuring the domains of Well-being in the Italian regions, and by INEGI for measuring Well-being in the Mexican States—seems to meet all the constraints listed above.

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