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Methodology for measuring triple helix performance

Abstract

Successes of a country at global or local levels depend heavily on the level of collaboration between Government, Industry, and Academia. The Triple Helix (TH) concept is a shift from industry-government dyad in the Industrial Society to growing relationship among university- industry-government in the Knowledge Society. Major dimensions of Tripple helix are lifelong learning, triple transition (climate, digital, demographic), gender equality and the future of employment. Despite huge volume of literature, there is still no single comprehensive methodology for measuring TH performance. The paper proposes two methods to measure TH-performance as composite index (CI) reflecting TH-performance of a country at a given year by arithmetic aggregations where scores of Likert items are transformed to continuous, equidistant and monotonic scores following Normal distribution (Method-1) and using multiplicative aggregation of ratio of raw score of an indicator at current year X_{ic} and the same for the base year (X_{i0}) and define $CI = \prod_i \frac{X_{ic}}{X_{i0}}$ (Method -2). Both methods satisfy desired properties including quantification of changes over time, relative importance of dimensions/components, no bias to developed or under-developed countries and finding TH-performance at world level by aggregating country-wise TH-scores. While arithmetic aggregation is more appealing, the multiplicative aggregation has additional features like time-reversal test, formation of chain indices, and distance from targets.

Keywords: Triple Helix; I-distance method; Normal distribution; Geometric mean; Sustainable Development Goals JEL Classification O11 · O38 · C44.

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Introduction

Human-scale competitiveness involves decent employment, better knowledge and skills, human centric business projects, sustainability, and no gender discrimination. To achieve such competitiveness, a country requires coordinated efforts among the three agents of Triple Helix: Industry, Academics (higher education institutions, universities), and Government administration. A low co-operation between industries and academics may lead to unsatisfactory progress in developments of research and technology and lack of effective govt. interventions may not lead to direction of focused developments with identified priorities which are necessary for a country to compete and meet multidisciplinary challenges of the Sustainable Development Goal (SDG) by 2030. Vivar-Simon et al.,[1] highlighted need for developing an agenda for the Triple Helix (TH) to achieve human-scale competitiveness along with identification of relevant set of indicators to monitor TH performance.

The Triple Helix concept is a shift from industry-government dyad in the Industrial Society to growing relationship among university-industry-government (UIG) in the Knowledge Society. The concept needs an analytical framework for better understanding of the dynamics of the Knowledge Society and active participations of policy-makers at national, regional levels in managing innovations and developing strategies. For example, India has emerged as an exporter of medical facilities from an importer of healthcare facilities within a span of few years by TH transformation.[2]

Interactions among the agents of the Triple Helix (TH) can be summarized as a model of government pull and responses from university and industry. Such interactions.[3] Industries, universities including higher education institutions and governments are the key players in accelerating competitiveness at national level since they make important contributions to sustainable economic growth, employment generation, and prosperity.[4] Roles of universities (knowledge production) in the Triple Helix framework involve conducting fundamental and empirical research, developing new technologies, conducting training and creating skilled workforce. Industry (wealth generation) plays a crucial role in the commercialization and application of research outcomes with trained and skilled workers and normative control is provided by the government. While, university is a provider of knowledgeable and qualified human capital, government indicates the prioritized areas and regulates social and economic issues like employment generation, access to education and health care facilities, etc. Thus, "entrepreneurial university" can contribute directly or indirectly to indicators of TH-performance of a country and are related to R&D, patent activities, technology, balance of payment (BoP), international trade, etc.

Accelerating cooperation among the agents that form the TH is important in achieving human-scale competitiveness. Limited number of high-level research and knowledge transfer by universities especially in underdeveloped countries were not found to be adequate to address socio-economic goals of a country.[5] Accordingly, demand for "entrepreneurial university" requiring interactions with government and business activities emerged as driver of regional and socio-economic development.[6,7] Despite huge volume of literature in entrepreneurial university studies, comprehensive methodology for measuring TH-performance by a single index is lacking.

Interrelated indicators of TH-performance can be extended further to Quadruple and Quintuple Helices incorporating innovations and knowledge for better understanding of trajectory to a region, especially for non-linear dynamics of technology and innovation. Quadruple and Quintuple Helices models have been used for further strategy development like EU-programs in Smart Specialization, Plan

S, Open Innovation 2.0, etc.[8] However, higher-order transitions like quadruple, quintuple, or N-tuple Helices) can be broken down to interacting Triple Helices.[9] The authors favoured simple model like TH than specifying more helices and making the models complex. Thus, Triple-Helix model can suffice to start with.

The paper proposes assumption free methods to measure TH-performance as composite index (CI) reflecting TH-performance of a country at a given year by arithmetic aggregations where scores of Likert items are transformed to continuous, equidistant and monotonic scores following Normal distribution (Method-1) and using multiplicative aggregation of ratio of raw score of an indicator at current year (X_{ic}) and the same for the base year (X_{i0}) and define $CI = \prod_i \frac{X_{ic}}{X_{i0}}$ (Method -2). Properties satisfied by the proposed indices discussed including assessment of TH-performance at world level by aggregating country-wise TH-scores.

Literature survey

OECD Framework of entrepreneurial university model emphasizes the following seven charters.[10]

- leadership and governance;
- organizational capacity;
- people and initiative;
- entrepreneurial development in teaching and learning;
- pathway for entrepreneurs;
- university-industry relationship for knowledge exchanges;
- international institutes;
- assessment of impact of entrepreneurial university
-

The challenges to meet SDGs imply that Triple Helix must face in implementation by 2030.[11,12] Both TH model and SDGs emphasize on socio-economic development requiring coordinated works by multi-stakeholders like creators, implementers and enablers for a better world. Advancement of knowledge-based economy and dissemination of socially organized knowledge are major drivers of socio-economic development. Lifelong learning at collective level act as a catalyst to increase productivity, employment opportunities and social cohesion,[13,14] which requires development of employment and economic policies. In the era of innovation and digitalization, university passed outs are required to lead the changes in productive systems aiming at satisfaction of economic and social objectives of the economy.[15] Industries try to bridge the gaps of skill and knowledge by training programmes or even introduction of special paper at PG-level as per requirements of one or a group of industries. Thus, better co-operation between universities and industries are needed to achieve synergy between training and up gradation of skills needed by professionals.[16,17]

Transfer of knowledge (teaching) and advancement of fundamental knowledge (research) at universities or higher educational institutes may not address adequately the goals of modern, knowledge-based economy and social goals of the regions.[5] Universities are expected to interact effectively with industrial and regional partners and develop partnerships with key stakeholders in public policy domains including government, representing many other communities of interest.[18] Thus, modern universities are increasingly playing role of public character and contributing to the society to achieve greater equality of opportunity; lifelong learning; undertaking public service functions and accelerate the process of socio-economic changes, keeping in mind that universities now-a-days have diversity of stakeholders and their missions. In other words, in the environment of globalization and knowledge-based society and economy, universities are attempting to find

(i) What should be our business? (Than what is our business?);

(ii) Who should be our students? (Than who are our students?);

(iii) What opportunities are there (Than what is our environment?)

(iv) How should we deploy our assets? (Than what are our resources?).[18]

Major dimensions of Tripple helix are lifelong learning, triple transition (climate, digital, demographic), generation of employment and gender equality.

Empirical relationship among innovation, transfer of knowledge and technology was found by regressing the capacity building in collaboration (CPS_{ss}) on total number of research materials (m_{SDS}) and the technology spillover in Indian region (ds_{ss})[10] However, the chosen independent variables failed to explain adequately variance of the dependent variable CPS_{ss} .

Assessment of TH-performance by Composite index-based approach like Data Envelopment Analysis (DEA) help in detecting the critical areas which are required to be improved to achieve higher performance.[19] Effectiveness of the method in combination with the I-distance method established.[20] Applied DEA using only six indicators, which are not sufficient to deal with complex problem like knowledge triangle policy in the EU countries.[21] However, DEA models are not without problems. The choice of variables can significantly influence the efficiency scores from DEA. Slow rate of convergence of efficiency of a DMU to 'absolute' efficiency; presence of outliers and noise (including symmetrical noise having zero mean) such as measurement error can result in significant problems and the best specification cannot be tested. In addition, DEA results are influenced by the number of input and output variables since increase in number of such variables tends to increase number of efficient units.[22] Cullinane et al.,[23] found different efficiency values under DEA-CCR and DEA-BCC models.

Considered 20 indicators distributed over four pillars with different weights to the pillars and found that *Technology balance of payments and Receipts* are the two most important indicators to reflect innovative activities of the country.[24] The authors used Composite I-distance (CIDI) measure of TH-performance at national level. The I-distance value for each pillar based on *k*-number of selected indicators $X_1, X_2, X_3 \ldots\ldots X_k$ was computed so that square of I-distance $D^2(r,s)$ between $e_r = (X_1, X_2, X_3 \ldots\ldots X_k)^T$ and $e_s = (X_{1s}, X_{2s}, X_3 \ldots\ldots X_{ks})^T$ is $D^2(r,s) = \sum_{i=1}^{k} \frac{X_{ir} - X_{is}}{\sigma_i^2} . \prod^{i-1}_{j=1} (1 - r_{ji..12.....}(j-1)^2$

where σ_i^2 is variance of X_i and $r_{ji..12.....}(j-1)$ is the partial correlation between X_i and X_j for j < i.[25] This was followed by computation of TH-performance index as weighted sum $D^2(r,s)$ of the four pillars where weight of the *i*-th indicator is given by $w_i = \frac{r_i}{\sum_{j=1}^{k} r_j}$ where r_i denotes correlation between *i*-th input value and I-distance value.

Steps to find I-distance are as follows:

I. Compute the discriminate effect of the most significant variable X_1 which provides the largest amount of information.

II. Take sum of value of the discriminate effect of X_2, not covered by X_1

III. Take sum of the discriminate effect of X_3, not covered by X_1 and X_2

IV. Repeat the procedure for all variables.

Major shortcomings are:

- Average of percentages is wrong, when the denominator $d_i \neq k * d_j$. Pooled average of 80% (80 out of 100) and 40% (48 out of 120) is 58.18% which is different from average of 80% and 40% i.e. 64%

- For an indicator associated with more than one functions say informative control and wealth generation, half of the value of the indicator is taken to both TH functions by Composite I-distance.

This artificial approach may mislead policy messages.

- Composite I-distance does not analyze the efficiency of the selected countries.

- Optimization of variance of the weighted sum not undertaken.

- Observed value of correlation (or partial correlation) depends heavily on group heterogeneity and may not confirm high comparability. Chakrabartty,[26] gave an example where $X \sim N(0,1)$ and $Y = \frac{1}{\sqrt{2\pi}} e^{\frac{-1}{2}X^2}$. Here, r_{XY} = - 0.93302 for $0 \leq X \leq 3.9$ and $r_{xy} = 0.0004$ for $-3.9 \leq X \leq 3.9$ indicating that homogeneity of data may underestimate or overestimate the correlation. Thus, value of (r) or R^2 may not always justify fitting of regression equation.

One solution could be to transform scores of each item/indicator to normally distributed scores to facilitate meaningful addition with knowledge of distribution of sum of the transformed scores.

- Use of partial correlation controlling effects of other variables is a novelty but interpretation of effect of partial correlations in I-distance is difficult.

- Weight assigned to an indicator varied significantly among the countries.

- Possibility of high TH performance scores by a country cannot be ruled out even if two other pillars are not equally developed.

- Relationships between a pair of agents like Industry-University, Industry-Government, and Government-University were not considered.

Selection of indicators

Choice of indicators depends on the purpose. If the objective is to study progress of TH performance, the chosen indicators could reflect results. If the purpose is to study factors of TH performance, the chosen indicators could be related to causes. For example, indicators relating to lifelong learning could be:

1. Identification of training needs, matching of skills between supply and demand, managing the transformation of work and industry (digitalization, robotisation, automation, robust and efficient renewable energy sources, promoting and achieving energy savings through approaches like educating the citizens and optimizing energy consumption, etc.)

2. Promoting networks, integrating education system and industries and encouraging specialization in training programmes for lifelong learning

3. Promoting specialized training to position the country as a technological leader

4. Filling demographic gaps in employment (covering the future demand of employees); and integrating migrants.

Future Employment indicators may cover action relating to:

- Integration of youth into the labour market and capacity development so as to attract and retain qualified technical personalities.

- Encouraging establishment of industries in the territory

- Promoting strategic cooperative projects and cross-border collaboration.

- Boosting R&D activities and to improve competitiveness;

- Encouraging technological entrepreneurship (start-up), intra-entrepreneurship, and diversification;

- Promoting reconciliation of personal, family, and working life.

- Encouraging positive parenting and co-responsibility.

- Encourage flexible working,

- Adapting the dynamics of companies

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Indicators selected by Jovanović et al.,[24] avoiding ordinal measures are:

Industry helix: Business expenditure on R&D (BERD) as percentage of GDP; Number of Business Enterprise researchers(BER) as percentage of national total, BER in terms of full-time equivalent employees (FTEs) that are specifically dedicated to research and development (R&D) and percentage of Gross expenditure on R&D (GERD) performed by the Business Enterprise sector.

Government helix: Percentage of GERD in the Government; Government researchers as percentage of national total; GOVERED as percentage of GDP; Percentage of GERD financed by Government; Percentage of GERD financed by Industry; Government researchers (FTE)

University helix: Percentage of GERD in the Higher education sector; Number of Higher education researchers as percentage of national total; Higher education expenditure (HERD)as percentage of GDP; Percentage of HERD financed by Industry; Higher Education researchers (FTE).

University- Industry - Govt. combined helix: Technology balance of payments: Receipts; Technology balance of payments: Payments; Total R&D person/thousand labour force; No. of "triadic" patent families; GERD per capita population.

Vivar-Simon et al.,[1] developed questionnaire to assess 19 selected challenges of TH using 10-point scale (1: strongly disagree to 10: strongly agree) which was responded by experts drawn from different fields of the three helices i.e. university helix, business helix, and public administration helix. The selected items were classified according to the four themes viz. Triple Transition, Lifelong Learning, Future Employment, and Gender Equality. However, number of items was different for different themes. The authors found that *eradicating gender-based violence* as the most critical challenge.

Major limitations of scales using summative scores of ordinal responses to K –point items where K= 3, 4, 5, 6,… are:

Scales differ with respect to chosen dimensions, length (numbers of items), width (number of response-categories), distributions of item scores, etc. and can influence assessment, policy issues, identification of critical areas, etc.

Ordinal discrete scores from Likert/Rating scales are not additive as they are not equidistant. Distance between successive response-categories is not constant i.e. equidistant property is not satisfied. Thus, addition of item scores is not meaningful.[27] Non-satisfaction of the equidistance assumption implies non-admissibility of mean, standard deviation (SD) correlation, etc.[28]

Meaningful addition of discrete random variables like $X + Y = Z$ requires $P(Z = z) = \mathrm{P}\ (\mathrm{X}=\ \mathrm{x},\ \mathrm{Y}=\ \mathrm{z}\ -\ \mathrm{x})$ and $P(Z \le z) = P(X + Y \le z) = \int_{-\infty}^{\infty}(\int_{-\infty}^{z} f_{X,Y}(x,t-x)dt)\ dx$ for continuous case. Thus, knowledge of probability density function (pdf) of X and Y and their convolution are needed.

Different responses to the items can generate tied scores and do not allow discrimination among such respondents.

Distribution of item scores and test scores are often found to be skewed

Summative scores assume equal importance to items and dimensions which contradicts different values of item-total correlations, different factor loadings, different correlations between pair of dimensions, etc.

In summative scores, low score of a dimension can be well compensated by high score in another dimension(s).

Possible solution is to transform scores of Likert items to continuous, equidistant and monotonic scores which can be normalized to follow $N(0,1)$ and further transformed linearly to follow normal with uniform score range and finding scale scores as sum of such scores.[29] Such transformations ensure meaningful arithmetic aggregations satisfying desired properties.

Gender equality

Gender equality is a hazard for socio-economic growth and is a basic human right. Cause and effect relationship exists between gender equality and economic growth.[30] Reduced gender inequality helps in better utilization of human capital by increasing female labour force participation (FLFP) and contributes in economic growth.[31] Elimination of All Forms of Discrimination against all women and girls everywhere is the SDG target 5.1 which is envisaged to be achieved by 2030. The Millennium Development Goals (MDGs) include among others promotion of equality and empowerment of women (http://www.un.org/millenniumgoals), and is also addressed in Addis Ababa Action Agenda,[32] 2030 Agenda for Sustainable Development,[33] which takes much broader view of gender equality than the MDGs. As per the review of the fifth goal of the SDG, a world with full gender equality is yet to be achieved.

Clearly, Gender equality is an objective to be achieved. Appropriate tool, process and aggregation of various gender related indices (GRIs) are needed along with impact of socio-economic developments on such GRIs. Possible indicators are:

Female empowerment Share of parliamentary seats held by women in national parliaments and in local governments, proportion of adult females with educational qualification of secondary education and above.

Labour force participation rate (LFPR): Separately for male and female and gap in gender-wise employment

Economic participation & opportunity: Wage equality across gender, equal opportunities for leadership at all levels of decision making in political, economic and public life.

Educational attainment: Women literacy rate, net enrolment rate at various levels of education like primary, secondary, tertiary levels separately for female.

Health and survival: Sex ratio at birth, life expectancy ratio of female and male, lower values of adolescent birth rate (ABR) reflecting risk of childbearing among females in the particular age group, decreasing trend of maternal mortality ratio (MMR) showing number of maternal deaths during a given time period per 100,000 live births.

Political empowerment: Percentage shares of seats by women in parliament, ministerial level, Head of state position occupied by female during say last 10 years.

Discrimination in the family (DFC): Exclusion, restriction of women in family that results in impairment of the recognition of human rights and fundamental freedoms of women.

Restricted physical integrity (RPI): Make women and girls vulnerable and limit their control over their bodies and reproductive autonomy.

Restricted access to productive and financial resources (RCL): Pervasive form of discrimination in social institutions which limit women's ownership and decision-making power over assets and financial tools and undervalue their status at work-place.

A number of GRIs have been developed by aggregating the selected indicators to a composite index(CI) like Gender Inequality Index (GII) by UNCTAD, Gender Gap Index (GGI) by WEF, OECD's Social Institution and Gender Index (SIGI), New Gender Equality Index (GEI) developed by the African Development Bank (AfDB), etc. Each index facilitates comparisons across countries and help policy-decisions. However, such GRI indices perform differently and are not comparable since they cover different dimensions with different number of indicators and also differ in terms of methods of normalization and aggregation. Ranks of countries get changed with changes in each of the abovementioned areas and explain different proportion of variation of economic aspects.[34] Even for the same time period, Barnat et al.,[36] found significant variation in country scores and ranks for GII, GGI and SIGI. Construction of methodologically sound gender related index (GRI) and/or gender similarity index (GSI) satisfying following illustrative desirable properties are needed:

- Reciprocity i.e. if men have 60% advantages over women, then women should have 40% disadvantages over men.

- Meaningful aggregation of Component scores to dimension score followed by aggregation to get GRI score for a country which may be aggregated to get World GRI score for a given time period. Aggregated scores at each stage should be monotonically increasing i.e. improvement in a dimension or component $\Longrightarrow$ Improvement in GRI for the country.
- Computation of relative importance of components and dimensions.
- Identification of critical dimensions and components where performances did not improve and require policy makers to adopt corrective measures.
- Should be able to detect changes of a country across time (Responsiveness)
- Facilitate statistical testing of equality of mean GRI/GSI of two countries for a given year and also at two different time periods for a country.

Proposed methods

The set up for measuring TH-performance as a composite index (CI) involves aggregations in the following stages:

Aggregation of item scores or indicator scores to get dimension / component scores like Future emplyment, Lifelong learning, Economic participation and opportunities of women, etc $\rightarrow$ *Aggregation of Component scores to get dimension scores like Gender equality, Univ. helix, etc.* $\rightarrow$ *Aggregation of helix scores to get performance of TH as CI*

Chosen dimension under a component could be in ordinal scales or in ratio scales or expressed in percentages. Aggregation of item/ indicators in continuous function needs to satisfy properties like:

$\mathcal{P}_1$: Aggregated scores of all indicators/items = Aggregated scores of components and

Aggregated scores of all components = Aggregated scores of dimensions and Aggregated scores of all dimensions = Aggregated scores of Helixes and Aggregated scores of all Helixes = Scores of TH-performance (CI)

$\mathcal{P}_2$: Known distribution of components, dimensions, Helixes and CI for testing of statistical hypothesis under parametric set up.

$\mathcal{P}_3$: Relative importance of dimensions, components and indicators to CI

$\mathcal{P}_4$: Identification of critical dimensions, components or indicators showing poor performances for necessary corrective policy action

$\mathcal{P}_5$: Assessment of changes over time for a single country or a sample of countries along with test of significance of the change.

$\mathcal{P}_6$: Drawing path of improvements/deteriorations across time for each country.

The above said six properties are satisfied by CI formed using arithmetic aggregation of transformed indicator scores ($\mathcal{P}_i$) following normal distributions (Method -1),[29] satisfying following properties:

- Score range of each item is uniform (from 1 to 100).
- Scores of i-th dimension $\mathcal{D}_i$ = sum of transformed scores of items related to the dimension and TH-score = $\sum_i \mathcal{D}$ = sum of all $\mathcal{P}_j s$. Thus, each of $\mathcal{D}_i$ and TH-scores follows normal distribution.
- Meaningful arithmetic aggregation. If $X \sim N\left(\mu_X, \sigma_X^2\right)$ and ($Y \sim N(\mu_Y, \sigma_Y^2)$) then $\left(X+Y\right) \sim N(\mu_X + \mu_Y, \sigma_X^2 + \sigma_X^2 + 2\sigma_{XY}$.
- Not affected much by outliers and thus, produces no bias for developed or underdeveloped countries
- Elasticity of a dimension by $\frac{\Delta TH}{\Delta \mathcal{D}_i}$ indicates relative importance of $\mathcal{D}_i$. Similarly, elasticity of each component of helix can be computed. Dimensions or components can be ranked with respect to elasticity.
- Assessment of progress/deterioration of TH-performance of i-th country in successive time years by $\frac{CI_{it} - CI_{i(t-1)}}{CI_{i(t-1)}} \times 100$ where CI_{it} denotes overall score of TH-performance at t-th year. Similarly, $\overline{CI_t} > \overline{CI_{(t-1)}}$ indicates progress for the group of countries in t-th year over *(t-1)*-th year.
- If $\frac{CI_{it} - CI_{i(t-1)}}{CI_{i(t-1)}} < 0$ implying deterioration, the dimension for which $\frac{\mathcal{D}_{it} - \mathcal{D}_{i(t-1)}}{\mathcal{D}_{i(t-1)}} < 0$ is the critical dimension requiring managerial decision.
- The plot of $\frac{CI_{it} - CI_{i(t-1)}}{CI_{i(t-1)}} \times 100$ across time points reflects path of TH-performance of a country across time, which provides another criterion for comparison of countries using longitudinal data.

Alternately, CI may be formed using multiplicative aggregation of ratio of raw score of an indicator at current year X_{ic} and the same for the base year (X_{i0}) and define $CI = \prod_i \frac{X_{ic}}{X_{i0}}$ (Method -2), satisfying the above said properties.

In addition, Method -2 enables aggregation of: indicators/ items, components, dimensions, helixes, ensuring reciprocity i.e. if women have X% disadvantages over men, then men to have (100 - X)% advantages over women. Method-2 can be applied without transforming raw scores to follow similar distribution say Normal and is applicable for data in ordinal scale, ratio scale and figures in percentages.

Additional properties satisfied by the Method-2 include:

- Time–reversal test i.e. $CI_{c0} \times CI_{0c} = 1$ where CI_{c0} is the TH-performance of a country at period C with respect to the base period.

- Formation of chain indices i.e. $CI_{20} = CI_{21} * CI_{10}$
- Trade-off among the components or dimensions or helixes are reduced significantly
- Instead of base period data, if previous year's data is taken, Method-2 gives improvement on Y-on-Y basis.
- Replacing the base period data by the SDG targets, the index will indicate how far the country is from the SDG goals at a particular time period.
- $\log CI = \sum_{i=1}^{n} logX_{ic} - \sum_{i=1}^{n} logX_{i0}$ boils down to additive model
- Possible to find first central moment (mean) and second central moment (variance) of $logCI$ for a country and also average of $logCI$ for the world as antilog of $\frac{\sum_{j=1}^{K} logCI_j}{K}$ for K-number of countries.
- $logCI$ of countries can be transformed by $Z_i = \frac{logCI_i - \overline{logCI}}{SD(logCI)}$ and Z-scores can further be transformed by linear transformation as $Y_i = (99)\left[\frac{Z_i - Min_{Z_i}}{Max_{Z_i} - Min_{Z_i}}\right] + 1$ so that $Y_i \in [1,100]$. Country-wise Y-scores can be used for better ranking and classification of the countries. Normally distributed Y-scores in fixed range help in meaningful addition and parametric analysis including estimation of population mean (μ), variance (σ^2), confidence interval of μ and to test statistical hypothesis of equality of mean CI of a country across time or different countries at a time period.

Empirical illustrations

Illustration of Method 1 (5-items each in 7-point scale) and Method 2 with four indicators are shown below with hypothetical data (Table-1, Table-2).

Table-1 Weights for equidistant scores and calculation of P-scores for Method 1

Description		Item-1	Item-2	Item-3	Item-4	Item-5	Total
Frequency	Max	21(L-5)	29 (L-4)	28 (L-4)	27(L-6)	20 (L–1)	
	Min	8 (L -3)	7 (L - 3)	5 (L-1)	6 (L- 2)	8 (L- 4)	
Weights to Response categories (RC)	RC-1	0.09134	0.053327	0.038103	0.04857	0.097037	
	RC-2	0.132253	0.124429	0.121295	0.12345	0.133426	
	RC-3	0.145891	0.148129	0.149026	0.148409	0.145555	
	RC-4	0.15271	0.15998	0.162891	0.160889	0.15162	
	RC-5	0.156801	0.16709	0.17121	0.168377	0.155259	
	RC-6	0.159528	0.17187	0.176756	0.173369	0.157685	
	RC-7	0.161477	0.175216	0.180718	0.176935	0.159418	
	Total of weights	1	1	1	1	1	
Raw scores(X)	Mean	4.45	4.31	4.08	4.88	4.01	21.73
	SD	1.871503	1.824054	1.580692	1.924221	2.217902	4.240755
Equidistant Score €	Mean	0.691954	0.700533	0.667923	0.818087	0.608179	3.486676
	SD	0.328293	0.356659	0.323231	0.381629	0.376632	0.790112
P-Score	Mean	51.18254	55.61505	51.81997	65.02	50.66501	274.3026
	SD	27.42968	30.09685	26.08143	31.74964	36.59538	68.81225

Table-2 Computation of Multiplicative aggregation (Method-2)

Individual	Base period values				Current period				$Y=\frac{X_{ic}}{X_{i0}} \times 100$
	X-1	X–2	X-3	X-4	X-1	X–2	X-3	X-4	
1	114	0.033003	32	25.7	115	0.031949	33	26.7	104.6245
2	120	0.038462	28	17.3	121	0.037037	29	18.3	106.3797
3	104	0.045455	32	76.3	105	0.043478	33	77.3	100.895
4	123	0.037736	20	16.4	124	0.036364	21	17.4	108.2242

Discussions

All the six desired properties are satisfied by each method including testing of statistical hypothesis. CI by Method-1and Method-2 avoiding scaling is in continuous scores and considers all components irrespective of units of measurements and help in better Ranking and classification of countries in mutually exclusive classes. To keep parity with general index, CI by each of Method-1 and Method-2 can be multiplied by 100 to indicate percentage CI. It is possible to find TH-performance at world level by aggregating country-wise TH-scores by both Method-1 and Method -2.

However, limitations of the proposed methods are as follows:

1. Missing data are not considered since it is beyond the scope of the current article
2. Method -2 fails if any item/component score is ≤ 0 or a target is equal to zero. Practical solution in those cases could be to replace zero by a small number $\varepsilon > 0$ (say0.0001)

3. If a new component is introduced at subsequent period, it involves estimation of values of the new component for the base period and each subsequent period.

Conclusions

The paper proposes methods for measuring TH-performance of a country at a given year of each dimension under a helix by additive aggregation (Method -1) and also by multiplicative aggregation (Method-2) which can be combined to find CI reflecting TH-performance of a country at a given year. While, component, dimension, helix scores follow normal distribution in Method-1, normality is not assured in Method-2. Trade-off among the dimensions/components are reduced. Presence of outliers do not affect the proposed indices and the indices are not biased either to developed or under-developed countries. In addition, each measure enables to find mean and SD for the countries considered in empirical studies. CI by method-2 can indicate current distance of a country from the SDG-goals. Each index facilitates computation of path of progress in TH-performance registered by a country across time. Attempts can be made to rank and classify the countries into mutually exclusive classes with respect to such progress paths.

Arithmetic aggregation is more appealing to policy makers. But, multiplicative aggregation has additional features like time-reversal test, formation of chain indices, and measuring distance from targets. Future investigations may be undertaken for empirical verification of properties of the proposed indices including rank robustness.

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Conflicts of interest

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Ethical statement

This is a methodological paper and no ethical approval is required.

Availability of data and material

Nil (The paper used hypothetical data).

Code availability

No application of software package or custom code.

Credit statement

Conceptualization; methodology; data analysis; writing and editing the paper by the **sole author.**

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