CHAPTER 3

JRC Statistical Audit of the Global Talent Competitiveness Index 2023

Jaime Lagüera González, Begoña Cabeza Martínez, Panagiotis Ravanos, Oscar Smallenbroek and Michaela Saisana

European Commission Joint Research Centre (JRC), Ispra, Italy

More than capital, individual skills and talents are the engines of growth and the driving forces that guide human beings towards the future. In today's complex and dynamic global economic system of intense competition, an environment where talent can be adequately and effectively attracted, developed and retained is of utmost importance for business's investment decisions and, by extension, for countries' sustainable growth.

Each year since 2013, INSEAD Business School has released the Global Talent Competitiveness Index (GTCI) in collaboration with the Descartes Institute for the Future (since 2021) and the Human Capital Leadership Institute (2013–2017, and again from 2022). The index aims to summarise complex and diverse concepts related to the availability of human capital and the relative strengths of nations in enabling talent to be developed, attracted, and retained, creating a single quantitative measure of talent competitiveness at the national level. In doing so, it raises conceptual and practical challenges that are discussed in an annual GTCI report.

This chapter concerns the GTCI report for 2023, the tenth annual edition of the index. It focuses on the practical challenges related to data quality and methodological choices made in the grouping of 69 indicators into 14 sub-pillars, six pillars, two sub-indices, and an overall index for 134 countries.

Overall, the GTCI 2023 has a very high statistical reliability. It has a Cronbach's alpha value of 0.97 and captures the single latent phenomenon underlying the six main dimensions of the GTCI conceptual framework. Country ranks are robust to methodological choices regarding the treatment of missing values, weighting, and aggregation rule, with a shift of less than or equal to 3 positions with respect to the simulated median in 94 percent of the countries included in this year's GTCI.

The added value of the GTCI lies in its ability to summarise different aspects of talent competitiveness in a more efficient manner than is possible when indicators and pillars are considered separately. In fact, between one-third and a half of the countries have a different rank position on the GTCI index compared to each of the six pillars.

The European Commission's Competence Centre on Composite Indicators and Scoreboards (COIN) at the Joint Research

Centre (JRC) has been invited to assess the statistical properties of the GTCI since its initial publication in 2013. This audit is the tenth such analysis of the GTCI performed by the JRC.

Overall, the JRC concludes that the GTCI 2023 framework is robust and reliable, with a statistically coherent and balanced multi-level structure. The analysis has been performed to ensure the transparency and reliability of the GTCI, and to enable policymakers to derive accurate and meaningful conclusions about human capital and national competitiveness, and potentially guide their choices on priority setting and policy formulation.

As with previous audits, this assessment of the GTCI 2023 focuses on two main issues: (1) the statistical coherence of the GTCI structure, and (2) the impact of key modelling assumptions on the GTCI scores and ranks.[1] The JRC analysis complements the reported country rankings for the GTCI, and for the Input and Output sub-indices, with confidence intervals to demonstrate the robustness of these ranks to the computation methodology (in particular, missing data estimation, weights, and aggregation formula).

Furthermore, the JRC analysis includes an assessment of the added value of the GTCI and a comparison with other global measures of talent attractiveness, competitiveness, and innovation. The 2023 version of the GTCI model is consistent with other international indicator frameworks measuring global attractiveness, competitiveness, and innovation at the national level. Furthermore, GTCI 2023 is shown to offer additional insights into nations' human capital and competitiveness compared to the other indices.

The practical aspects addressed in this chapter relate to the statistical soundness of the GTCI, which should be considered a necessary, although not necessarily sufficient, condition for a sound index. Given that the present statistical analysis of the GTCI will be mostly, but not exclusively, based on correlations, the correspondence of the GTCI to a real-world phenomenon needs to be critically addressed, since "correlations need not necessarily represent the real influence of the individual indicators on the phenomenon being measured".[2]

The validity of the GTCI relies on the combination of both statistical and conceptual soundness. In this respect, the GTCI has been developed following an iterative process that went back and forth between the theoretical understanding of human capital and talent competitiveness on the one hand, and empirical observations on the other.

STATISTICAL COHERENCE IN THE GTCI FRAMEWORK

The JRC undertook an initial assessment of the GTCI 2023 data set in July 2023. No critical issues were identified in the 2023 model during this preliminary phase of the audit.

The underlying concepts and indicator framework that are used to describe global talent competitiveness in the GTCI 2023 have remained largely the same as those in the 2022 edition, although there are some adjustments in this year's version. In particular, one indicator (3.2.4. Formal and non-formal education and training) has been excluded from the 3.2. Lifelong Learning sub-pillar of the Grow pillar, as 58 percent of countries in the 2022 GTCI report had missing data.

A second indicator, 4.1.5. Vulnerable employment, has been included in the 4.1. Sustainability sub-pillar of the Retain pillar. The Vulnerable employment indicator adds a labour-focused aspect to the 4.1. Sustainability sub-pillar. Country rankings for 2023 are similar to those of 2022. In particular, all countries in the top-20 positions in the 2022 report also feature within the top 20 in the 2023 edition. This pattern also holds for 19 of the countries ranked in the bottom 20 positions.

Following the iterative process during which the index was fine-tuned, the assessment of the statistical coherence in the final version of the GTCI 2023 followed four steps:

Step 1: Relevance

Indicators were selected for their relevance to a specific pillar on the basis of the literature review, expert opinion, country coverage, and timeliness. To represent a fair picture of country differences, indicators were scaled either at the source or by the GTCI team.

Step 2: Data Checks

The data used are the most recently released. Forty-seven of 69 indicators have updated data since the 2022 GTCI report was compiled. Overall, data for 56 indicators refer to the years 2022 or 2021. Only three indicators (1.2.6 Urbanisation, 3.1.4 Reading, maths, and science, and 4.1.3 Brain retention) have data from 2018 or earlier. The cut-off year was set at 2012. Countries included in GTCI 2023 have data availability of at least 80% at the index level, and 60% at the sub-pillar level. Compared to the previous year's report, no additional country was excluded from the dataset, while Uzbekistan was added.

As a result, the GTCI 2023 dataset comprises 134 countries and 69 indicators and has 93.8% data coverage. This is a slight improvement over the 93% coverage in the 2022 report. Country data availability is at least 82% at the Input sub-index level and 63% at the Output sub-index level. Again, both are improvements over the 2022 report. Data availability at the indicator level is good: of the 69 indicators only two have data availability slightly below 60%. These are 2.1.1 FDI regulatory restrictiveness and 3.1.4. Reading, maths and science, both of which are available for approximately 59 percent of countries.

The GTCI development team identified potentially problematic indicators that could bias the overall results as those having absolute skewness greater than two and kurtosis greater than 3.5.[3] These indicators were treated either by Winsorisation or, in the case of more than five outliers, by taking the natural logarithm.[4] These criteria have been adopted since the first release of the GTCI, in line with the JRC-COIN's recommendations.

Step 3: Statistical Coherence

The JRC's analysis of the statistical coherence of the GTCI 2023, consists of a principal component analysis to study the structure of the data, a multi-level analysis of the correlations of indicators, and a comparison of GTCI rankings with its pillars and with other similar indices. This latter investigation demonstrates the added

value of the GTCI both in comparison with its component pillars and to other relevant indices on talent attractiveness, competitiveness, and innovation.

1. Principal Component Analysis and Reliability Item Analysis

Principal component analysis (PCA) was used to assess the extent to which the conceptual framework is compatible with statistical properties of the data. PCA confirms the presence of a single statistical dimension (i.e., one principal component with an eigenvalue significantly greater than 1.0) in all 14 sub-pillars, that capture between 45% (2.2 Internal Openness) and 90% (1.1 Regulatory Landscape) of the total variance in the underlying indicators.

A more detailed analysis of the correlation structure within and across the six GTCI pillars confirms that the sub-pillars are more correlated with their own pillar than with any other. This suggests that the allocation of sub-pillars to pillars in the GTCI is consistent from both a conceptual and a statistical perspective. Furthermore, all correlations within a pillar are positive and well above 0.7, which suggests that 50% or more of the variance in the GTCI pillar scores can be explained by an underlying sub-pillar (see Table 1). The lowest correlation of a sub-pillar to its pillar is 0.84, (between sub-pillar 5.1. Employability and pillar 5. Vocational and Technical Skills). These results show that the GTCI conceptual grouping of sub-pillars into pillars is statistically valid and that the six pillars are statistically well balanced.

The six pillars also share a single statistical dimension that captures 87% of the total variance, and the six correlation coefficients are quite high and very similar to each other, ranging from 0.90 (Attract pillar) to 0.96 (Enable pillar). The latter suggests that the six pillars contribute in a balanced way to the variation of the GTCI scores, as envisaged by the development team: all six pillars are assigned equal weights when aggregated to the GTCI. The reliability of the GTCI, as measured by its Cronbach's alpha value, is very high, at 0.97—well above the 0.70 threshold for a reliable aggregate.[5]

An important part of the analysis relates to clarifying the importance of the Input and Output sub-indices with respect to the variation of the GTCI scores. The GTCI is built as the simple arithmetic average of the four Input sub-pillars and the two Output sub-pillars. This implies that the Input sub-index has a weight of 67% while the Output sub-index has a weight of 33%. However, this does not translate to the Input sub-index being twice as important as the Output sub-pillar in determining the variation of the GTCI scores. In fact, the correlation coefficient between the GTCI scores and the Input or Output sub-index is 0.99 and 0.98, respectively, which suggests that the sub-indices are effectively placed on an equal footing as envisaged by the developers.

Overall, the above results demonstrate that the grouping of indicators into sub-pillars, pillars, and an overall index is statistically coherent, and that the GTCI has a balanced structure in which the six pillars are equally important in determining the variation in GTCI scores.

2. Importance of the Indicators in the GTCI Framework

The GTCI and its components are built as the simple arithmetic averages of the underlying indicators. Developers and users of composite indicators often consider that the weights assigned to the indicators coincide with the indicators' importance in

Table 1

Statistical coherence in the GTCI: Correlations between sub-pillars and pillars

	SUB-PILLAR	ENABLE	ATTRACT	GROW	RETAIN	VOCATIONAL AND TECHNICAL SKILLS	GLOBAL KNOWLEDGE SKILLS
INPUT	1.1 Regulatory Landscape	0.95	0.88	0.84	0.85	0.80	0.85
	1.2 Market Landscape	0.91	0.72	0.87	0.77	0.79	0.82
	1.3 Business and Labour Landscape	0.93	0.83	0.83	0.77	0.77	0.81
	2.1 External Openness	0.76	0.93	0.70	0.71	0.69	0.72
	2.2 Internal Openness	0.83	0.89	0.77	0.77	0.71	0.75
	3.1 Formal Education	0.82	0.68	0.92	0.82	0.78	0.85
	3.2 Lifelong Learning	0.78	0.68	0.90	0.64	0.64	0.72
	3.3 Access to Growth Opportunities	0.88	0.84	0.92	0.85	0.83	0.86
	4.1 Sustainability	0.88	0.82	0.85	0.96	0.85	0.87
	4.2 Lifestyle	0.78	0.74	0.77	0.96	0.80	0.81
OUTPUT	5.1 Mid-Level Skills	0.75	0.70	0.73	0.88	0.91	0.77
	5.2 Employability	0.73	0.66	0.72	0.59	0.84	0.64
	6.1 High-Level Skills	0.82	0.78	0.82	0.83	0.79	0.96
	6.2 Talent Impact	0.88	0.78	0.88	0.85	0.78	0.96

Source: European Commission, Joint Research Centre (2023).

Note: The values are the bivariate Pearson correlation coefficients (n = 134). Shaded values represent the coefficients between sub-pillars and the respective pillar based on the GTCI conceptual framework. Values greater than 0.70 within the shaded areas are desirable as they imply that the pillar captures at least 50% (≈ 0.70 × 0.70) of the variation in the underlying sub-pillars and vice-versa.

the index. However, the correlation structure of the indicators and their variances also impact an indicator's importance, thus weights are often not equivalent to an indicators importance within an index.

This section assesses the importance of all 69 indicators at the various levels of aggregation in the GTCI structure. The squared Pearson correlation coefficient, otherwise known as the *coefficient of determination* R^2, is used as a statistical measure of the importance of indicators in an index. The importance of the selected indicators is taken to be equivalent to the contribution of those indicators to the variation of the aggregate scores, whether those are sub-pillars, pillars, sub-indices, or the overall GTCI. The overarching consideration made by the GTCI development team was that all indicators should matter at all levels of aggregation. This is confirmed by an examination of the importance measures of the 69 indicators, which are given in Table 2.

For example, variations across countries in the scores of indicator 1.1.4 Regulatory quality can explain 94% of the variance in the respective sub-pillar score (1.1 Regulatory Landscape), 85% of the variance in the respective pillar (1. Enable), 86% of the variance in the Input sub-index, and 85% of the variance in the overall GTCI scores. Similarly, country variations in indicator 6.1.1. Tertiary educated workforce explains 77% of the variance in the sub-pillar, 6.1 High-Level Skills; 65% in its respective pillar, 6. Global Knowledge Skills; 67% in the Output sub-index; and 65% in GTCI scores. In addition, variations among countries in the newly added indicator, 4.1.5 Vulnerable employment, can explain at least 66% of the variation in its respective sub-pillar

Table 2

Importance measures for the indicators at each level of the GTCI structure

	PILLAR	SUB-PILLAR	VARIABLE	SUB-PILLAR	PILLAR	INPUT/OUTPUT	GTCI
INPUT	1. Enable	1.1 Regulatory Landscape	1.1.1 Government effectiveness	93%	84%	85%	84%
			1.1.2 Rule of law	96%	82%	83%	82%
			1.1.3. Political stability	74%	55%	58%	55%
			1.1.4 Regulatory quality	94%	85%	86%	85%
			1.1.5 Corruption	93%	78%	80%	78%
		1.2 Market Landscape	1.2.1 Extent of market dominance	61%	41%	42%	41%
			1.2.2 Domestic credit to private sector	54%	44%	44%	44%
			1.2.3 Cluster development	72%	48%	48%	48%
			1.2.4 R&D expenditure	60%	53%	50%	53%
			1.2.5 ICT infrastructure	73%	64%	62%	64%
			1.2.6 Urbanisation	53%	50%	50%	50%
		1.3 Business Landscape	1.3.1 Labour rights	31%	23%	24%	23%
			1.3.2 Labour-employer cooperation	57%	43%	45%	43%
			1.3.3 Professional management	68%	52%	53%	52%
			1.3.4 Relationship of pay to productivity	45%	40%	40%	40%
			1.3.5 Enterprise software	47%	30%	30%	30%
			1.3.6 Cloud computing	68%	52%	52%	52%
			1.3.7 Firms with website	58%	69%	70%	69%
	2. Attract	2.1 External Openness	2.1.1 FDI regulatory restrictiveness	23%	12%	13%	12%
			2.1.2 Financial globalisation	70%	56%	58%	56%
			2.1.3 Migrant stock	69%	37%	38%	37%
			2.1.4 International students	68%	37%	36%	37%
			2.1.5 Brain gain	35%	21%	22%	21%
		2.2 Internal Openness	2.2.1 Tolerance of minorities	52%	29%	32%	29%
			2.2.2 Tolerance of immigrants	25%	11%	13%	11%
			2.2.3 Social Mobility	54%	56%	57%	56%
			2.2.4 Economic empowerment of women	46%	24%	26%	24%
			2.2.5 Gender parity in high-skilled jobs	41%	31%	31%	31%
			2.2.6 Leadership opportunities for women	43%	40%	40%	40%

(continued on next page)

Table 2 (*continued*)

Importance measures for the indicators at each level of the GTCI structure

PILLAR		SUB-PILLAR	VARIABLE	SUB-PILLAR	PILLAR	INPUT/OUTPUT	GTCI
INPUT	3. Grow	3.1 Formal Education	3.1.1 Vocational enrolment	35%	18%	18%	18%
			3.1.2 Tertiary enrolment	64%	60%	58%	60%
			3.1.3 Tertiary education expenditure	59%	51%	51%	51%
			3.1.4 Reading, maths, and science	76%	61%	58%	61%
			3.1.5 University ranking	64%	50%	50%	50%
		3.2 Lifelong Learning	3.2.1 Business school ranking	69%	35%	36%	35%
			3.2.2 Prevalence of training in firms	39%	13%	14%	13%
			3.2.3 Employee development	57%	57%	58%	57%
		3.3 Access to Growth Opportunities	3.3.1 Delegation of authority	54%	51%	51%	51%
			3.3.2 Youth inclusion	61%	48%	47%	48%
			3.3.3 Use of virtual social networks	75%	65%	65%	65%
			3.3.4 Use of virtual professional networks	76%	67%	69%	67%
	4. Retain	4.1 Sustainability	4.1.1 Pension coverage	69%	47%	47%	47%
			4.1.2 Social protection	71%	67%	67%	67%
			4.1.3 Brain retention	31%	36%	38%	36%
			4.1.4 Environmental performance	69%	66%	67%	66%
			4.1.5 Vulnerable employment	73%	66%	64%	66%
		4.2 Lifestyle	4.2.1 Personal rights	51%	33%	35%	33%
			4.2.2 Personal safety	85%	70%	68%	70%
			4.2.3 Physician density	80%	63%	62%	63%
			4.2.4 Sanitation	68%	55%	54%	55%
OUTPUT	5. Vocational and Technical Skills	5.1 Mid-Level Skills	5.1.1 Workforce with secondary education	61%	26%	32%	26%
			5.1.2 Population with secondary education	75%	33%	40%	33%
			5.1.3 Technicians and associate professionals	78%	71%	73%	71%
			5.1.4 Labour productivity per employee	62%	78%	76%	78%
		5.2 Employability	5.2.1 Ease of finding skilled employees	50%	17%	18%	17%
			5.2.2 Relevance of education system to the economy	71%	43%	43%	43%
			5.2.3 Skills matching	34%	52%	56%	52%
			5.2.4 Highly educated unemployment	32%	8%	11%	8%
	6. Global Knowledge Skills	6.1 High-Level Skills	6.1.1 Workforce with tertiary education	77%	65%	67%	65%
			6.1.2 Population with tertiary education	75%	52%	56%	52%
			6.1.3 Professionals	78%	75%	77%	75%
			6.1.4 Researchers	69%	72%	73%	72%
			6.1.5 Senior officials and managers	53%	33%	39%	33%
			6.1.6 Digital skills	24%	14%	13%	14%
		6.2 Talent Impact	6.2.1 Innovation output	84%	73%	72%	73%
			6.2.2 High-value exports	43%	23%	25%	23%
			6.2.3 Software development	76%	82%	82%	82%
			6.2.4 New business density	47%	32%	31%	32%
			6.2.5 Scientific journal articles	79%	77%	76%	77%

Source: European Commission Joint Research Centre (2023).

Note: The values are the squared Pearson correlation coefficients, expressed as percentages (n = 134 countries). It is reassuring that almost all 69 variables in this 2023 edition are found to have a noteworthy impact of at least 10% on the GTCI variance and the variances of the respective sub-indices, pillars, and sub-pillars. The single indicator (5.2.4 Highly educated unemployment) for which the coefficients are less than 10% is shaded in white.

(4.1 Sustainability), pillar (4. Retain), the Input sub-index, and GTCI scores.

As shown in Table 2, variations in an indicator can explain between 23% and 96% of the variation in the respective sub-pillar, and between 11% and 86% of the variations in the respective Output or Input sub-Index. Almost all the 69 indicators in the 2023 GTCI edition are found to have a noteworthy impact on the GTCI: that is, variations in an indicator can explain at least 10% of the variance in the GTCI. The only exception is the 5.2.4. Highly educated unemployment indicator: while influential at the sub-pillar level (5.2 Employability), where it explains 32% of the variation of the scores, variations in this indicator can explain only 8% of the variation of the GTCI scores, which is slightly below the 10% threshold. These results are similar to the 2022 GTCI edition, where only one variable could not explain more than 10% of the GTCI. The fact that all but a few indicators are found to be influential at all levels of aggregation in the GTCI 2023 is in line with the careful revisions of the GTCI framework that its developers have undertaken in previous years.

3. Added Value of the GTCI

Very high levels of statistical reliability among the main components of an index can also be the result of redundancy of information. In this sense, the high correlation observed between the GTCI and its six sub-pillars suggests that each sub-pillar provides the same information, which would make aggregation unnecessary.

However, this is not the case in the GTCI. In fact, the overall GTCI 2023 country ranking differs significantly from any of the rankings within the individual six pillars: at least 36 percent of the 134 countries included in the 2023 edition have a position in the overall GTCI that differs from their rank in a particular pillar by 10 positions or more (see Table 3). This goes up to 55 percent of countries when the ranking of the GTCI is compared to that of the individual pillar 2. Attract (see Table 3). Again, this highlights the added value of aggregating the six pillars to obtain the overall GTCI and its informative summary of the six pillars. This result also shows the value of taking components into account on their own merit. In doing so, country-specific strengths and bottlenecks in human capital and talent competitiveness can be identified and used as an input for evidence-based policymaking.

The GTCI 2023 has also been compared with the latest available edition of three relevant international indices, using the most recent rankings extracted from these projects' websites (see Table 4).[6] These are: the 2022 Global Innovation Index from the World Intellectual Property Organization (WIPO); the 2023 Global Attractiveness Index from The European House - Ambrosetti; and the 2022 World Competitiveness Index from the International Institute for Management Development (IMD).

The correlation of rankings between the GTCI 2023 and all three indices is equal to or greater than 0.85, which suggests that the GTCI conceptual framework is consistent with the frameworks used to develop the other three indices. This is both an expected and a desirable outcome, since the concept of talent competitiveness relates to a country's potential for innovation and outcomes of innovation processes, and consequently its attractiveness and competitiveness as an investment destination.

Despite being highly correlated, however, the difference in rank between the GTCI and three alternative indices, is greater than 10 positions for 39 percent of countries in the Global Innovation Index, 67 percent in the Global Attractiveness Index, and 30 percent in the World Competitiveness Index. This indicates that the GTCI 2023 offers additional insights into nations' human capital and competitiveness compared to other indices.

Step 4: Qualitative Review

Finally, the GTCI results were evaluated by the development team and external experts to verify that the overall results are, to a great extent, consistent with current evidence, existing research, or prevailing theory. This work covered overall country classifications as well as relative performances in the Input and Output sub-indices.

These statistical tests and the positive outcomes regarding the statistical soundness of the GTCI notwithstanding, it is important to mention that the GTCI has to remain open to future improvements as better data, more comprehensive surveys and assessments, and new relevant research studies become available.

Table 3

Distribution of differences between pillar and GTCI rankings

	GTCI INPUT SUB-INDEX				GTCI OUTPUT SUB-INDEX	
Rank differences with respect to the GTCI 2023	Enable	Attract	Grow	Retain	Vocational and Technical Skills	Global Knowledge Skills
30 or more positions	3%	10%	7%	4%	7%	7%
20 to 29 positions	10%	16%	10%	4%	9%	9%
10 to 19 positions	25%	29%	27%	26%	30%	20%
10 or more positions*	**38%**	**55%**	**43%**	**34%**	**46%**	**36%**
5 to 9 positions	22%	17%	24%	29%	23%	28%
Less than 5 positions	34%	24%	29%	31%	28%	33%
0 positions	7%	4%	4%	6%	3%	4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: European Commission Joint Research Centre (2023).
* This row is the sum of the previous three rows.

Table 4

Difference in rankings between the GTCI 2023 and other international indices

Differences in ranking with respect to the GTCI 2023	Global Innovation Index 2022 (Cornell, INSEAD, WIPO)	Global Attractiveness Index 2023 (The European House Ambrosetti)	World Competitiveness Index 2022 (IMD)
30 or more positions	6%	12%	0%
20 to 29 positions	8%	19%	7%
10 to 19 positions	26%	36%	23%
10 or more positions*	**39%**	**67%**	**30%**
5 to 9 positions	33%	16%	27%
Less than 5 positions	26%	16%	32%
0 positions	2%	2%	12%
Total	**100%**	**100%**	**100%**
Pearson correlation coefficient with the GTCI	0.92	0.82	0.84
Spearman rank correlation coefficient with the GTCI	0.90	0.85	0.85
Common countries with the GTCI	125	129	60

Source: European Commission Joint Research Centre (2023).
Notes: The comparison between the GTCI and the other indices was based on the common set of countries.
*This row is the sum of the previous three rows.

One consideration for future versions of the GTCI would be to search for alternatives to the indicators which do not include recent data. In particular, the indicators 1.2.6 Urbanisation and 4.1.3 Brain retention are currently based on data from 2018, while the 5.1.4. Labour productivity per employee indicators refers to forecast data.

IMPACT OF MODELLING ASSUMPTIONS ON THE GTCI RESULTS

Every country's score in the overall GTCI and the Input and Output sub-indices depends on modelling choices: the six-pillar structure, the selected indicators, the choice to impute or not the missing data, the algorithm used for imputation, and the weights and aggregation method, among other elements. These choices are based on expert opinion, for example in the case of selection of indicators, or on common practice as is the case for min-max normalisation in the [0,100] range. They are driven by statistical analysis, for example in the treatment of outliers, or simplicity (for example, no imputation of missing data). Robustness analysis undertaken by the JRC aims at assessing the simultaneous and joint impact of these modelling choices on the rankings. The data are assumed to be error-free, as potential outliers and errors were corrected during the computation phase.

As suggested in the relevant literature on composite indicators,[7] the robustness assessment of the GTCI was based on a combination of a Monte Carlo experiment and a multi-modelling approach that considered three modelling choices: pillar weights, missing data, and the aggregation formula. This uncertainty analysis aims to respond, to some extent, to possible criticisms that the country scores associated with aggregate measures are generally not calculated under conditions of certainty, even though they are frequently presented as such.

While the term *multi-modelling* refers to testing alternative assumptions—that is, alternative aggregation methods and missing data estimation methods—the Monte Carlo simulation explored the issue of weighting. It comprised 1,000 runs, each corresponding to a different set of weights for the six pillars, randomly sampled from uniform continuous distributions centred in the reference values. The choice of range for the weights' variation was driven by two opposite needs: to ensure a wide enough interval to have meaningful robustness checks, and to respect the rationale of the GTCI, which places equal importance on all six pillars. Given these considerations, the limit values of uncertainty intervals for the pillar weights are: 15% to 35% for the four pillars in the Input sub-index; and 40% to 60% for the two in the Output sub-index (see Table 5). For the calculation of the GTCI, the limit values of uncertainty intervals for all six pillar weights are 6% to 26%. In all simulations, sampled weights are rescaled so that they always sum to 1.

For transparency and replicability, the GTCI development team opted not to estimate the missing data (only 6.2% of data were missing from the data set of 134 countries and all 69 indicators). The 'no imputation' choice, which is common in similar contexts (for example, in the Global Innovation Index and the European Skills Index), might encourage countries to not report low data values. The 'no imputation' choice in an arithmetic average means that it is equivalent to replacing an indicator's missing value for a given country with the respective mean of the other indicators that are being aggregated. Hence the available indicators data in the incomplete pillar may dominate, sometimes biasing the ranks up or down. To test the impact of this assumption, the JRC also estimated missing data, using the Expectation Maximisation (EM) algorithm.[8]

Regarding the aggregation formula, decision-theory practitioners have challenged the use of simple arithmetic averages because of their fully compensatory nature, in which a comparatively high advantage for a few indicators can compensate for a comparative disadvantage for many indicators.[9] As discussed in the previous section, the arithmetic averaging formula received statistical support for the development of the GTCI; however, the geometric average was considered as a possible alternative. This average is a partially compensatory approach that rewards

Table 5

Uncertainty analysis for the GTCI 2023: Missing data, aggregation, and pillar weights

		REFERENCE	ALTERNATIVE
I. Uncertainty in the treatment of missing values		**No estimation of missing data**	**Expectation Maximisation (EM)**
II. Uncertainty in the aggregation formula at pillar level		**Arithmetic average**	**Geometric average**
III. Uncertainty in the weights			
GTCI sub-index	Pillar	Reference value for the weight (within the sub-index)	Distribution assigned for robustness analysis (within the sub-index)
Input	Enable	0.25	U[0.15, 0.35]
	Attract	0.25	U[0.15, 0.35]
	Grow	0.25	U[0.15, 0.35]
	Retain	0.25	U[0.15, 0.35]
Output	Vocational and Technical Skills	0.50	U[0.40, 0.60]
	Global Knowledge Skills	0.50	U[0.40, 0.60]
		Reference value for the weight (when calculating the overall GTCI)	Distribution assigned for robustness analysis (when calculating the overall GTCI)
Overall GTCI	All six pillars	0.16	U[0.06, 0.26]

Source: European Commission Joint Research Centre (2023).

countries with similar performance in all pillars and motivates those countries with uneven performance to improve in those pillars in which they perform poorly and not just in any pillar.

Four models were tested based on the combination of no imputation versus EM imputation, and arithmetic versus geometric average, combined with 1,000 simulations per model (random weights versus fixed weights), for a total of 4,000 simulations for the GTCI and each of the two sub-indices. See Table 5 for a summary of the uncertainties considered in the GTCI 2023.

Uncertainty Analysis Results

The main results of the robustness analysis are shown in Figures 1a-1c, with median rankings and 90% confidence intervals computed across the 4,000 Monte Carlo simulations for the GTCI, the Input sub-index, and the Output sub-index respectively. In each of these figures, countries are ordered from best to worst according to their rank in the corresponding index, while a blue dot corresponds to each country's simulated median rank. Error bars represent the 90% interval across all simulations for each country. Table 6 shows the published rankings and the 90% confidence intervals that account for uncertainties in the missing data estimation, the pillar weights, and the aggregation formula. All published country ranks are within the simulated intervals, and these are narrow enough for most countries (less than or equal to 10 positions) to allow meaningful inferences to be drawn.

GTCI ranks are shown to be within the limits of most scenarios considered and robust to changes in the imputation method, pillar weights, and the aggregation formula. Assuming the median rank across the simulated scenarios is representative of these scenarios, then the GTCI rank is close to the median rank for 94% of the countries—differing by three positions or less. This suggests that the GTCI is a suitable summary measure.

Furthermore, the confidence intervals of less than or equal to 10 positions for 96 percent of the countries implies that the GTCI ranks are also robust to changes in the pillar weights, the imputation method, and the aggregation formula for the vast majority of the countries. Robustness has improved compared to the 2022 version of the GTCI, in which confidence intervals less than or equal to 10 positions were observed in the ranking for 71 percent of included countries.

Results for the Input and Output sub-indices are also robust and representative of the most scenarios considered. The rankings on the Input Sub-index are close to the median position (diverging by three positions or less) with intervals of less than or equal to 10 positions for 98 percent of the 134 countries considered. Similarly, rankings on the Output Sub-index are also close to the median rank for 85 percent of countries, with intervals of less than or equal to 10 positions for 82 percent of countries.

Overall, country ranks in the GTCI and its two sub-indices are robust to changes in the pillar weights, the imputation method, and the aggregation formula for the majority of countries considered. Table 6 reports the GTCI country ranks, and those of the sub-indices, together with the simulated intervals (90% of the 4,000 scenarios) to better demonstrate the robustness of these ranks to the computation methodology.

Sensitivity Analysis Results

To complement the uncertainty analysis, sensitivity analysis was used to identify which of the modelling assumptions have the highest impact on country ranks. Figure 2 plots the GTCI, the Input sub-index and the Output sub-index rankings against the rankings resulting from one-at-a-time changes either at the imputation methodology (no imputation of missing data versus imputation using the EM algorithm) or at the aggregation formula used at the last stage of aggregation (arithmetic versus geometric average).

Both the GTCI and its two sub-indices are robust to the changes in methodological assumptions, as illustrated by the relatively high correlations in ranking (the lowest correlation is 0.993) and the comparatively low calculated average change in ranking positions (the largest is 2.81 positions).

The most influential methodological assumption is the aggregation formula and this is particularly so for the Output sub-index, given that a lower correlation of ranks indicates

Figure 1a

Robustness analysis (GTCI rank vs. median rank, 90% confidence intervals)

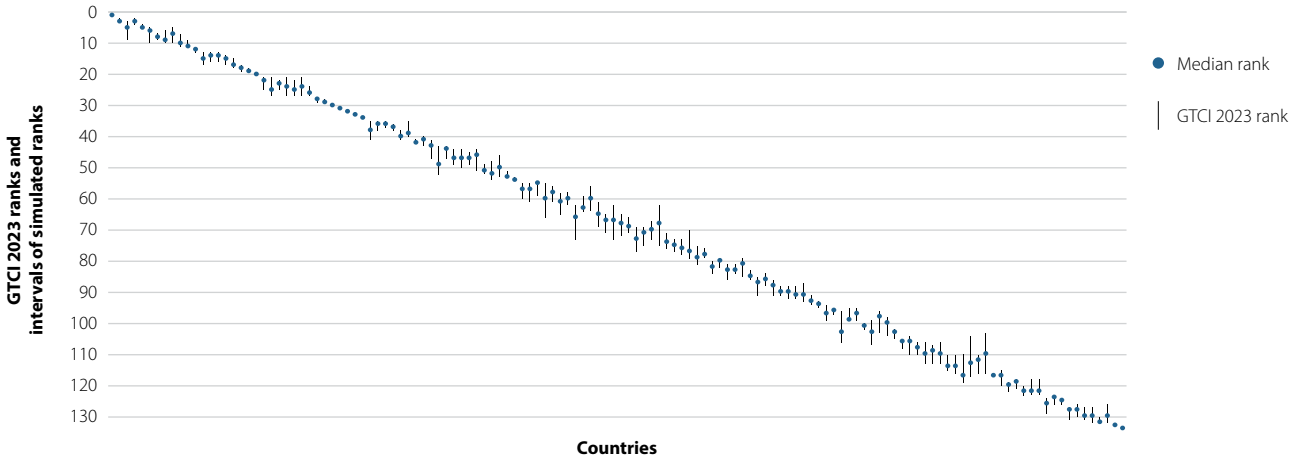


Figure 1b

Robustness analysis (Input rank vs. median rank, 90% confidence intervals)

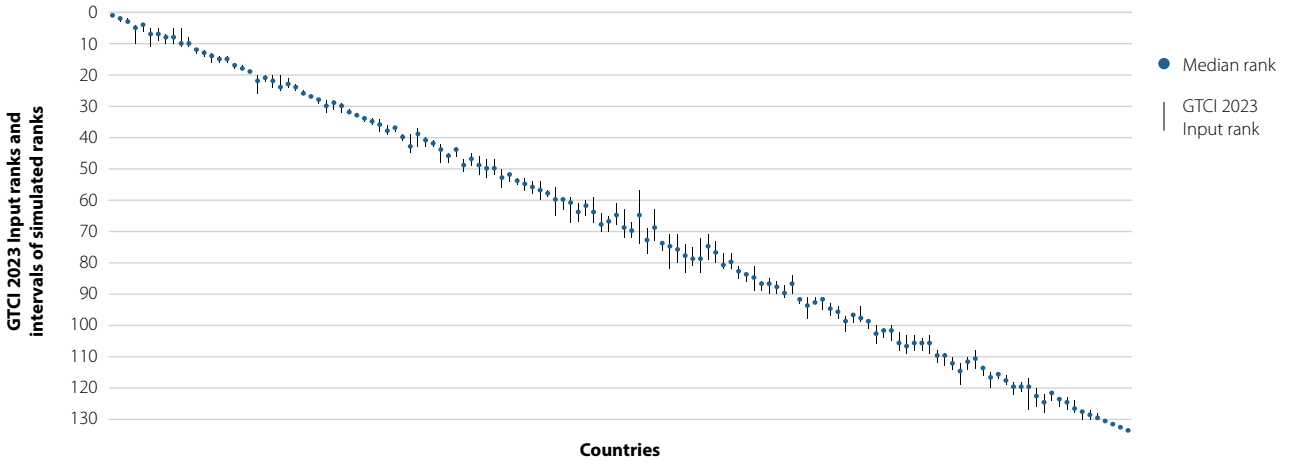
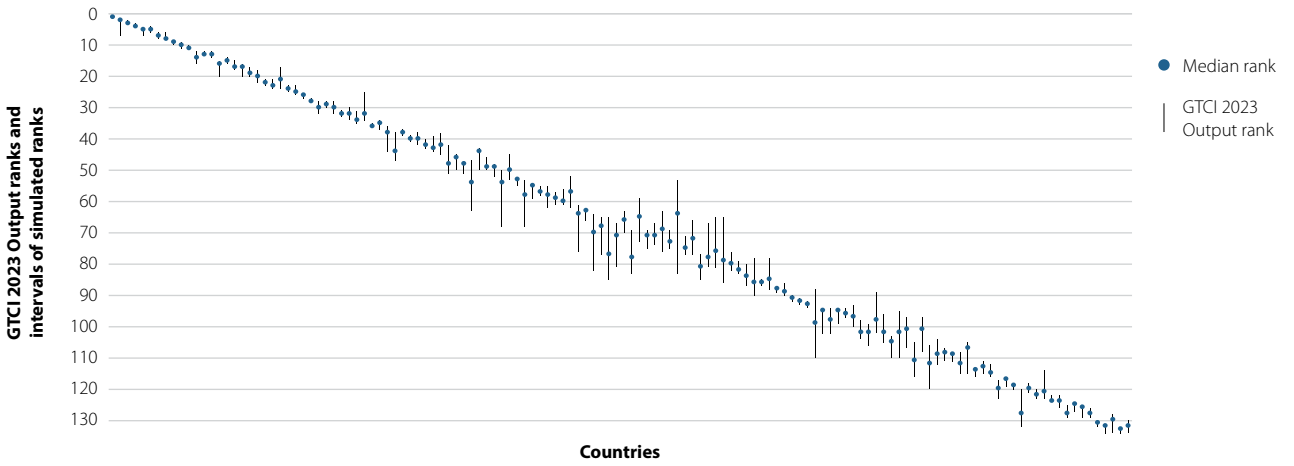


Figure 1c

Robustness analysis (Output rank vs. median rank, 90% confidence intervals)



Source: European Commission Joint Research Centre (2023).

Notes: The Spearman rank correlation between the median rank and the GTCI 2023 rank is 0.999 (n = 134); between the median rank and the GTCI 2023 Input rank it is 0.999; and between the median rank and the GTCI 2023 Output rank it is 0.997. Median ranks and intervals are calculated over 4,000 simulated scenarios combining random weights, imputation versus no imputation of missing values, and geometric versus arithmetic average at the pillar level.

Table 6

Country ranks and 90% confidence intervals for the GTCI 2023 and its Input/Output sub-indices

	GTCI 2023		INPUT SUB-INDEX		OUTPUT SUB-INDEX	
	RANK	INTERVAL	RANK	INTERVAL	RANK	INTERVAL
Switzerland	1	[1, 1]	1	[1, 1]	3	[2, 3]
Singapore	2	[2, 3]	6	[5, 11]	1	[1, 1]
United States	3	[3, 9]	4	[4, 10]	2	[2, 7]
Denmark	4	[2, 4]	2	[2, 3]	5	[5, 7]
Netherlands	5	[4, 5]	3	[2, 3]	14	[12, 14]
Finland	6	[5, 10]	5	[4, 6]	10	[9, 11]
Norway	7	[7, 9]	11	[8, 11]	4	[3, 4]
Australia	8	[6, 10]	8	[7, 10]	8	[6, 8]
Sweden	9	[5, 10]	9	[5, 10]	7	[6, 8]
United Kingdom	10	[7, 11]	7	[5, 9]	9	[9, 10]
Luxembourg	11	[9, 11]	10	[5, 11]	11	[10, 11]
Ireland	12	[12, 13]	12	[12, 13]	16	[14, 16]
Canada	13	[13, 17]	14	[13, 16]	15	[15, 20]
Germany	14	[13, 16]	13	[12, 14]	19	[17, 20]
Iceland	15	[13, 16]	19	[19, 19]	6	[4, 6]
Belgium	16	[14, 17]	16	[14, 16]	17	[15, 18]
Austria	17	[15, 18]	15	[14, 16]	20	[18, 22]
New Zealand	18	[17, 19]	17	[17, 18]	23	[17, 24]
France	19	[18, 19]	18	[17, 18]	21	[21, 23]
Estonia	20	[20, 20]	25	[23, 25]	18	[16, 20]
Malta	21	[21, 25]	23	[20, 25]	25	[23, 26]
United Arab Emirates	22	[21, 27]	20	[20, 26]	27	[27, 28]
Czech Republic	23	[22, 25]	26	[25, 26]	22	[21, 24]
South Korea	24	[21, 27]	31	[29, 32]	12	[12, 16]
Israel	25	[22, 27]	32	[31, 32]	13	[12, 13]
Japan	26	[21, 27]	22	[20, 24]	34	[25, 34]
Portugal	27	[24, 27]	24	[21, 24]	30	[28, 32]
Slovenia	28	[28, 29]	27	[27, 27]	24	[23, 25]
Spain	29	[28, 29]	21	[20, 22]	44	[38, 45]
Cyprus	30	[30, 30]	29	[28, 32]	26	[26, 27]
Lithuania	31	[31, 31]	28	[28, 29]	32	[30, 34]
Italy	32	[32, 32]	30	[28, 31]	35	[35, 36]
Latvia	33	[33, 33]	35	[34, 36]	29	[28, 30]
Chile	34	[34, 34]	33	[33, 33]	40	[39, 41]
Qatar	35	[35, 41]	36	[34, 38]	45	[42, 51]
Slovakia	36	[35, 38]	39	[39, 41]	33	[31, 35]
Poland	37	[35, 37]	43	[41, 43]	28	[28, 32]
Hungary	38	[36, 38]	42	[40, 43]	31	[31, 33]
Greece	39	[38, 41]	37	[36, 39]	53	[45, 53]
China	40	[35, 40]	41	[37, 43]	43	[39, 44]
Brunei Darussalam	41	[41, 42]	46	[43, 46]	37	[36, 44]
Malaysia	42	[40, 43]	48	[45, 49]	36	[34, 37]
Uruguay	43	[41, 47]	34	[34, 35]	71	[69, 75]
Bahrain	44	[43, 52]	40	[39, 45]	57	[55, 58]
Croatia	45	[43, 47]	47	[47, 51]	42	[40, 43]

(continued on next page)

Table 6 (*continued*)

Country ranks and 90% confidence intervals for the GTCI 2023 and its Input/Output sub-indices

	GTCI 2023		INPUT SUB-INDEX		OUTPUT SUB-INDEX	
	RANK	INTERVAL	RANK	INTERVAL	RANK	INTERVAL
Georgia	46	[44, 49]	45	[45, 48]	50	[46, 50]
Costa Rica	47	[44, 50]	38	[37, 38]	68	[63, 70]
Saudi Arabia	48	[45, 49]	51	[47, 52]	38	[38, 47]
Bulgaria	49	[44, 51]	50	[47, 53]	49	[43, 50]
Montenegro	50	[49, 52]	52	[50, 56]	46	[45, 50]
Mauritius	51	[48, 54]	44	[42, 48]	59	[57, 61]
Russia	52	[46, 53]	57	[54, 60]	39	[37, 39]
Serbia	53	[51, 53]	54	[53, 55]	47	[47, 51]
Romania	54	[53, 54]	58	[57, 59]	51	[48, 52]
Armenia	55	[55, 60]	59	[56, 65]	54	[53, 55]
Albania	56	[55, 61]	49	[46, 52]	69	[69, 83]
Belarus	57	[55, 59]	71	[69, 77]	41	[38, 42]
Azerbaijan	58	[55, 66]	63	[60, 65]	52	[50, 68]
Oman	59	[56, 61]	53	[51, 54]	65	[65, 77]
Trinidad and Tobago	60	[58, 65]	61	[59, 67]	55	[53, 68]
Argentina	61	[58, 62]	55	[53, 57]	63	[62, 66]
Uzbekistan	62	[62, 73]	74	[71, 82]	48	[47, 63]
Kuwait	63	[59, 64]	56	[54, 58]	77	[66, 77]
Ukraine	64	[56, 64]	60	[59, 63]	61	[52, 62]
Moldova	65	[61, 69]	69	[67, 72]	58	[55, 62]
Jamaica	66	[65, 71]	66	[65, 70]	62	[61, 76]
Kazakhstan	67	[62, 73]	65	[64, 70]	75	[53, 83]
South Africa	68	[65, 72]	64	[59, 67]	79	[67, 81]
Brazil	69	[66, 71]	67	[61, 68]	76	[71, 77]
Jordan	70	[69, 77]	62	[61, 67]	86	[85, 87]
North Macedonia	71	[69, 75]	77	[75, 81]	60	[56, 61]
Colombia	72	[67, 73]	72	[63, 73]	72	[67, 74]
Botswana	73	[62, 75]	70	[57, 74]	80	[65, 81]
Mexico	74	[71, 76]	68	[63, 72]	83	[79, 83]
Viet Nam	75	[73, 77]	75	[71, 80]	74	[69, 75]
Mongolia	76	[73, 78]	73	[73, 76]	81	[65, 86]
Lebanon	77	[70, 79]	87	[85, 90]	56	[54, 59]
Cabo Verde	78	[75, 81]	76	[74, 83]	78	[77, 85]
Thailand	79	[76, 79]	80	[73, 80]	82	[76, 82]
Indonesia	80	[80, 84]	81	[77, 82]	85	[78, 90]
Türkiye	81	[79, 82]	83	[81, 85]	73	[63, 76]
Peru	82	[81, 86]	78	[72, 83]	88	[87, 89]
Bosnia and Herzegovina	83	[81, 84]	86	[86, 89]	67	[67, 81]
Philippines	84	[79, 85]	90	[84, 90]	70	[59, 73]
Ecuador	85	[83, 86]	82	[77, 82]	91	[91, 93]
Kyrgyzstan	86	[85, 91]	89	[87, 91]	84	[80, 87]
Panama	87	[84, 88]	79	[71, 79]	98	[93, 100]
Egypt	88	[86, 91]	93	[91, 93]	64	[64, 82]
Dominican Republic	89	[88, 91]	88	[86, 90]	90	[90, 92]
Sri Lanka	90	[88, 92]	94	[91, 95]	66	[65, 85]

(continued on next page)

Table 6 (*continued*)

Country ranks and 90% confidence intervals for the GTCI 2023 and its Input/Output sub-indices

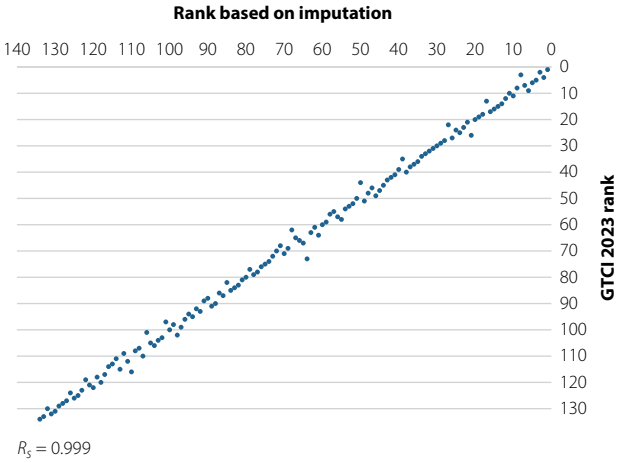
	GTCI 2023		INPUT SUB-INDEX		OUTPUT SUB-INDEX	
	RANK	INTERVAL	RANK	INTERVAL	RANK	INTERVAL
Paraguay	91	[88, 92]	85	[81, 89]	97	[94, 97]
Tunisia	92	[87, 93]	91	[91, 93]	87	[78, 88]
Namibia	93	[91, 94]	84	[83, 86]	104	[95, 110]
Bolivia	94	[93, 95]	95	[93, 97]	96	[94, 99]
Ghana	95	[94, 99]	96	[94, 98]	102	[96, 105]
El Salvador	96	[95, 97]	98	[96, 99]	95	[94, 102]
Gambia	97	[96, 106]	92	[91, 98]	119	[118, 120]
Kenya	98	[95, 99]	107	[104, 108]	92	[92, 94]
Morocco	99	[95, 99]	99	[94, 99]	107	[97, 108]
Eswatini	100	[100, 102]	97	[97, 102]	113	[105, 115]
Laos	101	[99, 107]	109	[108, 112]	94	[94, 102]
Algeria	102	[96, 103]	108	[103, 109]	101	[89, 102]
India	103	[98, 104]	106	[103, 108]	105	[97, 107]
Guatemala	104	[102, 105]	103	[100, 105]	110	[107, 111]
Honduras	105	[105, 108]	102	[101, 104]	116	[112, 116]
Cambodia	106	[104, 110]	100	[99, 101]	118	[117, 119]
Nepal	107	[106, 110]	113	[110, 114]	100	[99, 106]
Zambia	108	[106, 113]	111	[110, 114]	103	[103, 110]
Pakistan	109	[107, 113]	110	[109, 113]	111	[108, 111]
Rwanda	110	[106, 113]	101	[100, 106]	123	[114, 123]
Côte d'Ivoire	111	[110, 115]	104	[102, 108]	122	[120, 123]
Senegal	112	[110, 116]	105	[103, 109]	121	[118, 121]
Benin	113	[110, 119]	112	[112, 119]	108	[106, 120]
Nigeria	114	[104, 117]	118	[116, 119]	93	[88, 110]
Nicaragua	115	[110, 116]	114	[108, 114]	112	[108, 115]
Iran	116	[103, 116]	121	[117, 127]	89	[86, 90]
Zimbabwe	117	[116, 117]	124	[121, 124]	99	[98, 104]
Cameroon	118	[115, 120]	120	[118, 121]	109	[104, 112]
Uganda	119	[119, 122]	119	[118, 122]	114	[113, 116]
Malawi	120	[118, 121]	117	[115, 117]	117	[117, 123]
Tanzania	121	[120, 123]	115	[113, 116]	129	[126, 129]
Lesotho	122	[118, 123]	116	[115, 120]	125	[122, 126]
Bangladesh	123	[118, 123]	122	[120, 126]	115	[111, 115]
Burundi	124	[124, 129]	126	[123, 127]	120	[120, 132]
Madagascar	125	[124, 126]	125	[123, 126]	124	[122, 124]
Mauritania	126	[124, 126]	131	[131, 131]	106	[105, 116]
Mali	127	[127, 131]	123	[122, 128]	130	[130, 132]
Guinea	128	[126, 130]	129	[127, 130]	126	[125, 129]
Burkina Faso	129	[127, 131]	127	[124, 128]	134	[130, 134]
Angola	130	[127, 132]	130	[128, 130]	132	[128, 134]
Mozambique	131	[130, 132]	128	[127, 130]	133	[132, 134]
Ethiopia	132	[126, 132]	132	[132, 132]	127	[125, 127]
Democratic Republic of the Congo	133	[133, 133]	133	[133, 133]	128	[126, 129]
Chad	134	[134, 134]	134	[134, 134]	131	[131, 134]

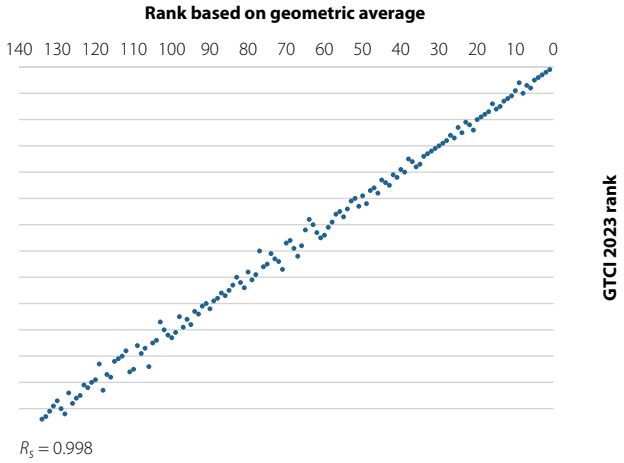
Source: European Commission Joint Research Centre (2023).

Figure 2

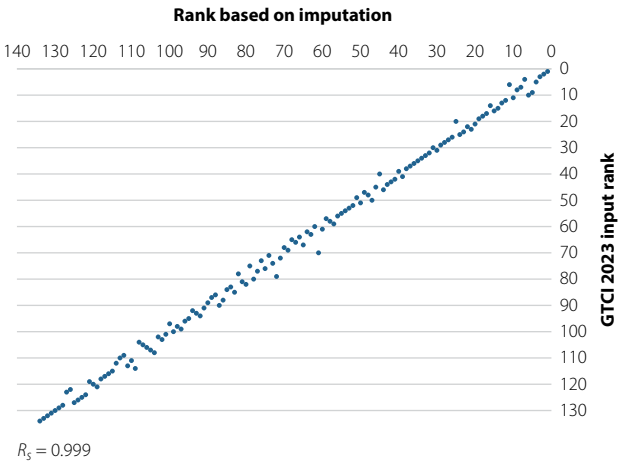
Sensitivity analysis: Impact of modelling choices

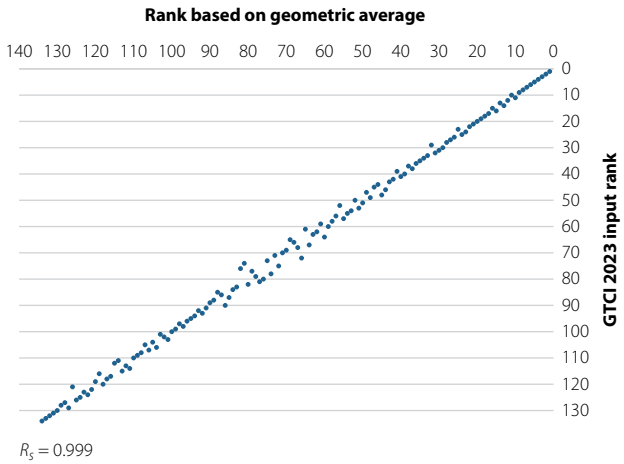
Global Talent Competitiveness 2023



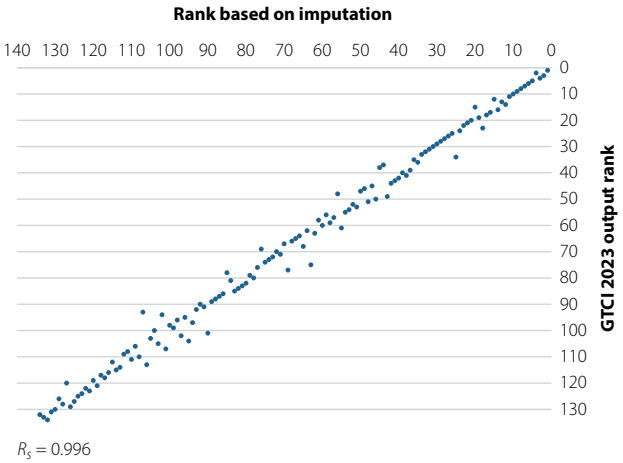


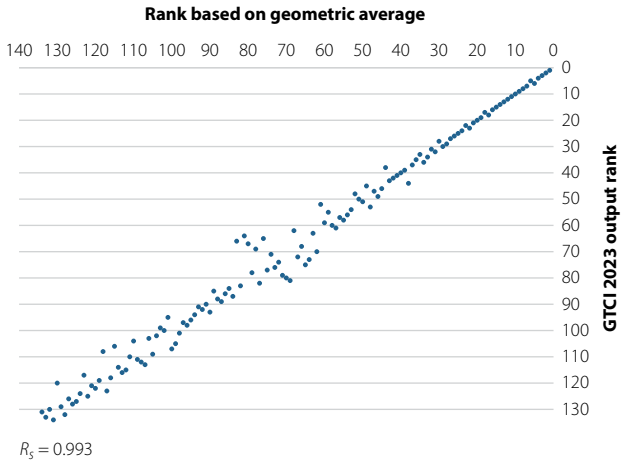
GTCI 2023 Input sub-index





GTCI 2023 Output sub-index





Source: European Commission Joint Research Centre (2023).
Note: R_S represents the Spearman rank correlation coefficient (n = 134).

greater sensitivity. Change in country ranks when considering geometric instead of arithmetic aggregation in the Output sub-index is on average 2.81 positions, while just seven percent of countries exhibit shifts in rank greater than 10 positions. In the most extreme of these cases, aggregating the Output pillars using a geometric instead of an arithmetic average causes Egypt and Sri Lanka fall by 17 positions in the ranking (from 64 to 81, and from 66 to 83 respectively), while Mongolia improves by 12 positions (from 81 to 69). However, these assumptions on the weights, aggregation method, and missing data estimation—primarily concern methodological choices and may be less influential overall than choices related to the background assumptions in the conceptual framework.[10]

Overall, the ranges of uncertainty in the final rankings are fairly modest. This suggests that the rankings of the overwhelming majority of the 134 countries in the overall GTCI 2023 and the Input and Output sub-indices are the result of the countries' own performance (as reflected in the underlying data) and not of the considered modelling choices.[11] Consequently, the JRC recommendation is not to alter the GTCI methodology, but to consider country ranks in the GTCI 2023 and in the Input and Output sub-indices within the 90% confidence intervals in order to take into account to what degree a country's rank depends on the modelling choices.

CONCLUSIONS

This year's edition of the Global Talent Competitiveness Index (GTCI) marks its tenth anniversary. Throughout the decade of annual publications, the GTCI intention has been to bring attention to the growing challenges that countries around the world face when developing, attracting and maintaining talent, and to highlight best practices in talent management. The JRC statistical audit has investigated the current GTCI framework to assess the statistical properties of the data and the methodology used in constructing the 2023 edition of the index. The JRC analysis suggests that the conceptualised structure is statistically coherent and balanced on multiple levels of the GTCI 2023.

The GTCI is not dominated by any pillar or sub-pillar. All underlying indicators contribute to the variation of the respective Input and Output sub-indices, and to the overall GTCI. Furthermore, the analysis offers statistical justification for the use of equal weights and arithmetic averaging at the various levels of aggregation. It shows that the GTCI is statistically reliable in its current form as the simple average of the six pillars (as measured by a high Cronbach's alpha value of 0.97).

It is reassuring that the majority of the 69 indicators considered in this 2023 edition are found to have a noteworthy impact of at least 10% on the GTCI variance. The only exception, 5.2.4 Highly educated unemployment, is also very close to this threshold, and can explain 8% of the GTCI variance. That nearly all indicators are found to be influential at all levels of aggregation in the GTCI 2023 is the direct result of the careful revision of the GTCI framework undertaken in previous years by the developers. A suggestion for future versions of the GTCI would be to consider alternatives for the indicators which do not include recent data. This refers mostly to indicators 1.2.6 Urbanisation and 4.1.3 Brain retention, which are currently based on data from 2018.

The country ranks in the GTCI and both its sub-indices are relatively robust to methodological assumptions related to the estimation of missing data, weighting, and aggregation formula. It is reassuring that, for a large majority of the countries included in the GTCI, the overall rank and those in the Input and Output sub-indices are the result of countries' own performance (as reflected in the underlying data) and not of the modelling choices. Consequently, inferences can be drawn for most countries in the GTCI.

Perfect robustness would not be desirable, as it would imply that the GTCI components are perfectly correlated and hence redundant, which is not the case for the GTCI 2023. In fact, one way in which the GTCI helps to highlight other components of human capital and talent competitiveness is by pinpointing the differences in rankings that emerge from a comparison between the GTCI and each of its six pillars.

In the analysis conducted by the JRC, the GTCI ranking differs from any of the six pillar rankings by 10 positions or more for at least 34 percent and up to 55 percent of all countries. This outcome demonstrates the added value of aggregating the six pillars to the GTCI, which helps to identify overall best practices in talent management across the world. It also highlights the importance of taking into account the individual pillars, sub-pillars, and indicators on their own merit. In doing so, country-specific strengths and bottlenecks in human capital and talent competitiveness can be identified and used as an input for evidence-based policymaking.

The auditing conducted herein has shown the potential of the GTCI 2023 for reliably identifying weaknesses and best practices and ultimately monitoring national performance in human capital development and the relative competitiveness of countries in talent management. Readers and policy analysts should go beyond the overall GTCI scores and ranks and consider the individual indicators and pillars on their own merit.

The GTCI cannot serve as the definitive yardstick for monitoring progress and performance on talent and competitiveness. Instead, it best represents an ongoing effort by INSEAD, the Descartes Institute for the Future and the Human Capital Leadership Institute to continuously adapt the GTCI framework to reflect improved and new data sources and the theoretical advances on how to leverage talent as a tool for competitiveness. In this way it can effectively contribute to policy discussions on the many challenges that national talent-management systems face in an increasingly competitive and talent-driven world.

ENDNOTES

1 The JRC analysis was based on the recommendations of the OECD and EC JRC (2008) *Handbook on Constructing Composite Indicators* and on more recent research from the JRC. The JRC auditing studies of composite indicators are available at https://knowledge4policy.ec.europa.eu/composite-indicators_en and https://composite-indicators.jrc.ec.europa.eu (all audits were carried out upon request of the index developers).

2 OECD & EC JRC (2008).

3 Groeneveld & Meeden (1984) set the criteria for absolute skewness above 1 and kurtosis above 3.5. The skewness criterion was relaxed to account for the small sample (134 countries).

4 These indicators are: 1.3.1 Labour rights; 2.1.4 International students; 6.1.5 Senior officials and managers; 6.2.2 High-value exports; and 6.2.4 New business density

5 See Nunnally (1978).

6 Comparison with these three indices has been adopted since the 2022 edition of the GTCI. At the time of writing, the 2023 version of the World Economic Forum's Global Competitiveness Index and of the Global Innovation Index are not available.

7 Becker et al. (2017); Paruolo et al. (2013); Montalto et al. (2020); Saisana et al. (2005), (2011); Saisana & Saltelli (2011); Saltelli et al. (2008); Vértesy (2016); Vértesy & Deiss (2016).

8 The Expectation-Maximization (EM) algorithm (Little & Rubin, 2002) is an iterative procedure that finds the maximum likelihood estimates of the parameter vector by repeating two steps: (1) The expectation E-step: Given a set of parameter estimates, such as a mean vector and covariance matrix for a multivariate normal distribution, the E-step calculates the conditional expectation of the complete-data log likelihood given the observed data and the parameter estimates. (2) The maximization M-step: Given a complete-data log likelihood, the M-step finds the parameter estimates to maximize the complete-data log likelihood from the E-step. The two steps are iterated until the iterations converge.

9 Munda (2008).

10 Saltelli & Funtowicz (2014).

11 As already mentioned in the uncertainty analysis, about 94% of the simulated median ranks for the GTCI are fewer than three positions away from the reported 2023 rank—this percentage is at 98% in the Input sub-index and drops to 85% in the Output sub-index.

REFERENCES

Becker, W., Saisana, M., Paruolo, P., & Vandecasteele, I. (2017). Weights and importance in composite indicators: Closing the gap. *Ecological Indicators* 80: 12–22.

The European House - Ambrosetti (2023). *The Global Attractiveness Index: the thermometer of a country's attractiveness*. 8th edition. Milan: The European House - Ambrosetti.

Groeneveld, R. A. & Meeden, G. (1984). Measuring Skewness and Kurtosis. *Journal of the Royal Statistical Society, Series D (The Statistician)*, 33, 391–399.

IMD (International Institute for Management Development). 2022. *IMD World Competitiveness Yearbook 2022*. Lausanne: IMD.

Little, R. J. A. & Rubin, D. B. (2002). *Statistical Analysis with Missing Data* (2nd ed.). New York: John Wiley & Sons.

Montalto, V., Tacao Moura, C. J., Langedijk, S., & Saisana, M. (2020). Culture counts: An empirical approach to measure the cultural and creative vitality of European cities. *Cities*, 89, 167–185. Available at https://doi.org/10.1016/j.cities.2019.01.014

Munda, G. (2008). *Social Multi-Criteria Evaluation for a Sustainable Economy*. Berlin Heidelberg: Springer-Verlag.

Nunnally, J. (1978). *Psychometric Theory*. New York: McGraw-Hill.

OECD & EC JRC (Organisation for Economic Co-operation and Development and European Commission Joint Research Centre). (2008). *Handbook on Constructing Composite Indicators: Methodology and User Guide*. Paris: OECD. Available at http://www.oecd.org/std/42495745.pdf

Paruolo, P., Saisana, M., & Saltelli, A. (2013). Ratings and rankings: voodoo or science? *Journal of the Royal Statistical Society*, A 176 (3), 609–634.

Saisana, M., D'Hombres, B., & Saltelli, A. (2011). Rickety numbers: Volatility of university rankings and policy implications. *Research Policy*, 40 (1): 165–177.

Saisana, M. & Saltelli, A. (2011). Rankings and Ratings: Instructions for Use. *Hague Journal on the Rule of Law*, 3 (2), 247–268.

Saisana, M., Saltelli, A., & Tarantola, S. (2005). Uncertainty and sensitivity analysis techniques as tools for the analysis and validation of composite indicators. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 168 (2), 307–323.

Saltelli, A. & Funtowicz, S. (2014). When All Models Are Wrong. *Issues in Science and Technology*, Winter 2014, 79–85.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., & Tarantola, S. (2008). *Global Sensitivity Analysis. The Primer*. Chichester, England: John Wiley & Sons.

Schneider, T. 2001. Analysis of Incomplete Climate Data: Estimation of Mean Values and Covariance Matrices and Imputation of Missing Values. *Journal of Climate*, 14, 853–871.

Vértesy, D. (2016, July). A Critical Assessment of Quality and Validity of Composite Indicators of Innovation. Paper presented at the OECD Blue Sky III Forum on Science and Innovation Indicators. Ghent, 19–21 September 2016.

Vertesy, D. & Deiss, R. 2016. The Innovation Output Indicator 2016. Methodology Update. EUR 27880. European Commission, Joint Research Centre.

WIPO (World Intellectual Property Organization). (2022). *Global Innovation Index 2022: What is the future of innovation-driven growth?* Geneva: WIPO. DOI 10.34667/tind.46596