IMPACT OF COMPENSABILITY AMONG INNOVATION PERFORMANCE INDICATORS ON COUNTRIES' RESULTS IN SII 2022

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Abstract

The importance of innovation for the future competitiveness of firms and economies is reflected in a large number of proposals for assessing innovation performance at the firm and national levels. National innovation performance is considered a multidimensional phenomenon and is often assessed by composite indicators (CI). The main objective of this paper is to show how changing the final aggregation method in the CI construction affects the ranking of EU countries in the latest EIS 2022 ranking. The different aggregation methods (additive, geometric, harmonic) and their impact on the ranking are analysed both at the level of the dimensions of innovation performance (framework conditions, investment, innovation activities, impacts) and the final composite indicator (CI). An explanation of the differences in the countries' ranking is based on the different rates of compensation of worse values by better values (among individual indicators and dimensions). The second aim is to identify the causes of unbalance among the sub-dimensions /(main types of activities). The decomposition of variance is regarded as a useful tool for the measurement of between-groups and within-groups variance at the countries' level. Cronbach's alpha is used to assess the internal consistency of the SII both at the level of the final composite indicator and the sub-dimensions of innovation performance.

Keywords: composite indicator, European Innovation Scoreboard, innovation performance, Summary Innovation Index

JEL Code: O3, O1, I2

Introduction

The general definition of innovation and the useful methods for measuring innovation performance are widely discussed for decades. While R&D inputs, the number of patents and their citations, and the number of new products entering the market can be considered key indicators of innovation performance at the firm level, innovation performance at the country level is reckoned as a multidimensional phenomenon and is often assessed by composite indicators (CI).

Composite indicators are preferred by policymakers who need relatively simple and comprehensive tools for the evaluation of countries' innovation performance. The Summary Innovation Index (SII) is published annually by European Commission in the European Innovation Scoreboard (EIS). This comprehensive tool is generally accepted for its ability to take into account different indicators of countries' innovation performance - from innovation inputs to innovation outputs (see groups of innovation activities in SII: Framework conditions, Investment, Innovation activities, Impacts) - and identify the pros and cons of national innovation systems in international comparison. When the results of composite indicators are examined, it is important to keep in mind their relatively complex design. The CI construction is based on several crucial decisions: choice of a framework (usually determined by theoretical models and experts' opinions), choice of suitable variables, choice of normalisation method, and choice of weighting system (i.e. decision about the aggregation method). Each sub-step in the construction of a composite indicator can influence the final value. Inappropriate choice of these sub-steps (concerning the declared meaning of the composite indicator) can lead to inaccuracies that distort the information value of the CI.

1 Literature review

1.1 How to measure innovation performance at a corporate and national level?

A large number of studies examine how to measure innovation performance at both crucial levels (firm, national). However, there is still no clear consensus either on a general definition of innovation that covers all economic sectors or on a set of indicators mapping innovation performance comprehensively. Gault (2018) attempts to address this gap by developing a conceptual framework that includes a systems approach to innovation and a general definition that is applicable in all economic sectors. The aim is not just to increase the number of institutional units that innovate, but to support social and economic outcomes, such as jobs and economic growth. Some studies focused on the measurement of innovation in firms (e.g. Brattström et al., 2018) highlight that an inappropriate method of measurement can obstruct or hinder innovation since "it pushes organizational members to focus their attention too narrowly". Brattström et al. (2018) identify two ideal types of measurement practices in firms (directional measurement and conversational measurement) and recommend using their suitable combination depending on the degree of ambiguity (it is difficult to interpret or distinguish issues and action alternatives). According to the aforementioned authors, conversational management should be preferred in situations of higher ambiguity (due to the emphasis on a bottom-up process, allowing organizational members to consider multiple issues and action alternatives simultaneously). Using case studies of two manufacturing firms, Nappi and Kelly (2022) validate their proposed model for measuring innovation performance. Their performance framework is based on the analysis of strengths and weaknesses across nine up-to-date dimensions and the definition of suitable action plans. Hagedoorn and Cloodt (2003) evaluated the innovative performance of a large international sample of nearly 1200 companies in four high-tech industries, using a variety of the following indicators: R&D inputs, patent counts, patent citations, and new product announcements. Their study finds out that a composite indicator based on the aforementioned four indicators captures a latent variable 'innovative performance' well.

1.2 The EIS methodology and some problematic aspects of measuring innovation performance

The EIS identifies four areas and twelve dimensions of innovation. In total, the latest ranking (EIS 2022) consists of 32 indicators, which are obtained from different sources (e.g. Eurostat, Scopus database, Community Innovation Survey, OECD patent data, ...). Each of the four areas (Framework conditions, Investment, Innovation activities, Impacts) includes the same number of indicators (8) and has the same weight (25%) in the Summary Innovation Index (SII), so each indicator in the SII has the same weight (1/32, i.e. 3, 125%). *Framework conditions* deal with the main drivers of innovation performance outside the firm. *Investments* monitor investments in the public and business sectors. *Innovation activities* monitor different aspects of innovation in the business sector. *Impacts* map the effects of firms' innovation activities. According to the EIS 2022 assessments, the EU member states are divided into four country groups: 1) innovation leaders (five Member States where performance is above 125% of the EU average), 2) innovation followers (seven Member States with a performance between 100% and 125% of the EU average), 3) moderate innovators (eight Member States where performance is between 70% and 100% of the EU average), and 4) catching-up countries (seven Member States that show a performance level below 70% of the EU average).

Corrente et al. (2023) regarded the SII as a suitable tool for comparing innovation in Europe but noted that the EIS lacks a suitable scheme for weighting the included indicators based on their relative importance. A key assumption of Corrente et al. (2023) is that meaningful composite innovation indicators need to take into account some fundamental aspects such as the interaction among the underlying indicators, the hierarchical structure of the indicators, robustness concerns related to the consideration of a range of variation in the adopted weights, and the involvement of a set of stakeholders who may focus their attention on different criteria. The critical view of Bielińska-Dusza and Hamerska (2021) on the SII can be summarized as follows: 1) the EIS methodology is not fully consistent with the theoretical assumptions; 2) the indicators adopted in the methodology represent only a certain part of the innovation activity; 3) a large number of indicators may cause difficulties in establishing interdependencies and correlations among variables; 4) he change in methodology (changes in indicators) complicates the comparison of results in time (Bielińska-Dusza and Hamerska, 2021). This paper aims to contribute to the search for a meaningful alternative to the current EIS methodology. Our next steps are as follows: 1) an explanation of our approach to data editing and aggregation; 2) a comparison of our results obtained by a different aggregation method with those obtained by the original methodology.

2 Aims and methods

The first aim of this paper is to compare the official ranking of EU countries in the latest EIS 2022 (SII) with the ranking obtained by using alternative methods of final aggregation (geoSII is the result of using the geometric mean, harmSII is the result of using the harmonic mean).

Mariani and Ciommi (2022) note that the use of the geometric mean is not decisive to fully balance the contributions of the single indicators (the geometric mean approach attributes the same value of composite indicator to two pairs of indicator values that have very different distributions and horizontal dispersions). OECD (2008) compares aggregation methods according to (1) suitability for excellent and poor performers: geometric aggregations reward countries that score higher, linear aggregations reward basic indicators in proportion to the weights, (2) degree of compensability: compensability is constant under linear aggregation, compensability is lower under geometric aggregation for composite indicators with low values. In terms of implications for an adequate economic policy in a given area, a country with low values of one indicator will need much higher values of the other indicators to improve its situation using geometric aggregation (OECD, 2008).

Table 1 provides a brief description of the aggregation methods used in this paper, including a comparison of compensation rates and an identification of their limitations (concerning indicator values). E.g. OECD (2008) or El Gibari (2018) emphasize that the additive aggregation methods allow total compensation of worse values by better values. Using the example of a simple composite indicator, Table 2 shows how different variability in input indicators (see countries X, Y and Z) and different degrees of compensability (see aggregation methods) affect the resulting CI value.

Tab. 1: Aggregation functions and different levels of compensation

Aggregation function	Formula	Level of compensation	Recommendations for using
additive	$score_c = \sum_{i=1}^{n} I_{ic} \cdot w_i$	total	If low-performing indicators can be fully compensated by high-performing indicators
geometric	$score_c = \prod_{i=1}^{n} I_{ic}^{w_i}$	partial	If decision-makers do not accept full compensation among indicators (worse performance even in only one indicator is penalized)
harmonic	$score_c = \frac{n}{\sum_{i=1}^{n} \frac{w_i}{I_{ic}}}$	Partial (less compared to geometric)	If decision-makers want to reduce the compensation more (compared to the geometric mean)

Source: Cinelli et al (2021), author's processing.
Note: $score_c$= composite score for alternative c; I_{ic}= the normalized value of indicator *i* for alternative *c*; w_i = weight of indicator *i*; geometric and harmonic means are usable only with normalized datasets containing positive numbers

Table 2 presents the results of the final index for three hypothetical countries. Their evaluation is based on the normalized values (on a scale 0-1) in two sub-dimensions. Country X has the greatest differences between dimensions (iA = 0.99, iB =0.01), country Z shows average performance on both dimensions and the performance of country Y is in the top quartile on dimension A and the bottom quartile on dimension B.

Tab. 2: Impact of different levels of compensation on the value of the final indicator

Alternative	Normalized indicators		Variance (s.d.)	Aggregation functions		
	i_A	i_B		additive	geometric	harmonic
Country X	0.99	0.01	0.480 (0.693)	0.5	0.099	0.02
Country Y	0.75	0.25	0.125 (0.354)	0.5	0.43	0.38
Country Z	0.5	0.5	0 (0)	0.5	0.5	0.5

Source: Cinelli et al (2021), author's processing.
Colour scale: the best performance is in white, the worst in grey. All other values are coloured proportionally by linear interpolation.

The simple example presented in Table 2 shows that the compensability decreases from the arithmetic mean to the geometric and harmonic mean. It is also clear that the level of penalization is higher when the variability between indicators is higher.

Our explanation of the differences in the countries' ranking relies on the different rates of compensation of worse values by better values at the following levels: 1) the whole sample of countries, 2) the groups of countries divided by innovation performance (emerging innovators, moderate innovators, strong innovators, innovation leaders), and 3) areas of innovation activities (Framework conditions, Investments, Innovation activities, Impacts). The second aim is to find out the causes of unbalance among and inside the areas (sub-dimensions). Decomposition of variance (at the countries' level) is applied for the measurement of interclass and intraclass (between-groups and within-groups) differences. Cronbach's alpha is used to assess the internal consistency of the SII at the following levels: 1) the final CI, and 2) the areas of innovation activities (Framework conditions, Investments, Innovation activities, Impacts). The arithmetic mean in sub-dimensions (we mean the arithmetic mean of all values in a given sub-dimension for all countries of the given countries' group) allows us to identify sub-dimension (areas) with: 1) a competitive advantage (the highest value could mean a competitive advantage), and 2) the smallest lag behind a typical innovation leader.

The range of variation and the standard deviation (s.d.) are regarded as suitable tools for explaining the differences in the ranking of countries. In the case of high range and high s.d., a relatively high rate of compensation can be expected if an additive method is used (for the final aggregation). A high range (and a high s.d.) for a given country, therefore, indicates a deterioration of the ranking if we use final aggregation methods that penalize different values among indicators. Unfortunately, alternative methods of final aggregation (geometric, harmonic mean) do not allow the calculation of the final CIs for countries with a minimum value of partial indicators (the min-max method of normalization assigns a zero value to the worst result). For the above reason, Bulgaria, Latvia, Portugal and Romania had to be excluded from the sample.

3 Results

Table 3 maps the competitive advantages of groups of innovators (emerging, moderate, strong, leaders) in the innovation performance areas (framework conditions, Investments, Innovation activities, Impacts). able 3 also provides an assessment of the internal consistency of innovation performance (see Cronbach's alpha) and permits the identification of countries for which a deterioration in the ranking can be expected using alternative aggregation methods.

Cronbach's alpha (C-alpha) was applied for checking whether the indicators within sub-dimensions (areas of innovation performance) measure "the same thing"[1]. The C-alpha values indicate that SII can be considered internally consistent even at the level of individual innovation performance domains.

Tab. 3: Cronbach's alpha and selected descriptive statistics in innovation dimensions

Country Group (innovators)	SII	Framework conditions	Investments	Innovation activities	Impacts
Arithmetic mean in dimensions					
Emerging	0.301	0.255	0.287	0.286	0.374
moderate	0.481	0.454	0.450	0.494	0.527
strong	0.618	0.601	0.557	0.637	0.679
leaders	0.720	0.761	0.735	0.705	0.677
Range in dimensions (max value of the indicator-min value of indicator)					
Emerging	0.883 (RO)	0.883 (RO)	0.708 (HR)	0.651 (HR)	0.727 (RO)
moderate	0.996 (EL)	0.788 (LT)	0.853 (EE)	0.866 (EL)	0.909 (EE)
strong	0.946 (CY)	0.724 (LT)	0.946 (CY)	0.733 (CY)	0.805 (IE)
leaders	0.869 (FI)	0.586 (FI)	0.854 (FI)	0.792 (SE)	0.754 (SE)
Standard deviation (s.d.) for a typical country in a given group					
Emerging	0.179	0.17	0.152	0.155	0.205
moderate	0.219	0.184	0.214	0.221	0.232
strong	0.237	0.182	0.272	0.197	0.232
leaders	0.214	0.182	0.255	0.192	0.219
Max s.d. (country. rank)					
Emerging	RO (27)	RO (27)	HR (17)	HR (21)	HU (21)
moderate	EL (24)	LT (26)	LT (27)	EL (27)	LT (26)
strong	LU (19)	CY (25)	CY (25)	CY(26)	IE(25)
leaders	FI (18)	FI (23)	FI (26)	SE (24)	SE (27)
Cronbach's alpha					
EU-27	0.9503	0.9159	0.8312	0.8682	0.7494

Source: European Commission (2022). author's processing.
Note: arithmetic mean in dimensions = arithmetic mean of all indicators in dimension (we use data of all countries in the given group of innovators)

[1] If all indicators are perfectly correlated, C-alpha is 1. In practice, C- alpha greater than 0.7 evaluates a given set of indicators as a reliable representation of the item being measured.

s.d. for a typical country in a given group of innovators = average value of s.d. for individual countries (we mean s.d. among indicators in a given innovation performance dimension)
Max s.d. (country, rank) = the ranking of the country is given in brackets (from the lowest to the highest s.d.), e.g. RO (27) means that Romania is the country with the highest s.d. in the EU 27

Innovation leaders have an absolute competitive advantage in three areas of innovation performance (Framework conditions, Innovation activities, and Investments), s.d. for a typical country indicates the potential compensation of worse values by better ones in Investment and Impacts. A deterioration in ranking can be expected for Finland (due to s.d. in Framework Conditions and Investment) and Sweden (as a result of s.d. in Innovation Activities and Impacts). *Strong innovators* have an absolute competitive advantage in Impacts (captures the employment, sales, and environmental effects of enterprises' innovation activities), s.d. for a typical country indicates the potential compensation of worse values by better ones in Investment and Impacts. A deterioration in ranking can be expected for Cyprus (due to high variability in Framework conditions, Investment and Innovation activities), Ireland (as a result of high s.d. in Impact) and Luxembourg (due to high s.d. in the whole SII).

Moderate innovators - as a result of their involvement in global European business chains - have a relative competitive advantage in Impacts. Standard deviation (s.d.) for a typical country indicates a higher degree of compensability in Impacts and Innovation activities. A worsening of the ranking can be expected for Greece (high s.d. in Innovation activities and overall high s.d.) and Lithuania (high s.d. in Framework conditions, Investments and Impact). *Emerging innovators* have the lowest scores in all areas of innovation performance, with typical countries having relatively lower s.d. among low indicator values. A relative advantage can be identified (again as a result of involvement in global European business chains) in the sub-dimension Impacts. S.d. for the typical country indicates a higher degree of compensability in Impacts and Framework conditions. A deterioration in the ranking can be expected for Romania (the highest s.d. in SII as a result of high s.d. in Framework conditions) Croatia (s.d. in Investments and Innovation activities) and Hungary (s.d. in Impacts).

Table 4 presents a summary of the following results: 1) ranking of countries according to different final aggregation methods; 2) ranking of countries based on s.d. (i.e. the propensity to offset between indicators); 3) variance decomposition (allowing to identify the source of variability - among or within innovation performance areas). The following commentary on Table 4 is focused on the results of the variance decomposition (the changes in country ranking are summarized in the Conclusion). Table 4 shows the homogeneity of *Innovative leaders* and the balanced results among the innovation sub-dimensions - the variation is concentrated within the innovation performance groups for all countries (in Investment for Denmark, Finland and Sweden; in Framework conditions for Belgium; in Impacts for the Netherlands).

Tab. 4: Countries'results_decomposition of variance, alternative final aggregation

Country		Interclass variance	Intraclass variance	s.d.	SII	geoSII	harmSII	s.d. rank	SII rank	geoSII rank	harmSII rank	1_2	1_3
Austria	AT	9.5	90.5	0.170	0.641	0.621	0.600	3	8	6	5	2	3
Belgium	BE	21.9	78.1	0.159	0.697	0.669	0.638	2	5	4	2	1	3
Bulgaria	BG	88.2	11.8	0.426	0.244			26					
Croatia	HR	66.2	33.8	0.348	0.359	0.298	0.224	23	21	22	22	-1	-1
Cyprus	CY	22.3	77.7	0.313	0.578	0.486	0.362	20	10	12	16	-2	-6
Czechia	CZ	22.3	77.7	0.212	0.501	0.461	0.421	6	14	14	12	0	2
Denmark	DK	21.2	78.8	0.242	0.730	0.692	0.641	12	3	1	1	2	2
Estonia	EE	22.3	77.7	0.250	0.541	0.488	0.412	13	12	11	13	1	-1
Finland	FI	17.5	82.5	0.269	0.734	0.674	0.570	18	2	3	6	-1	-4
France	FR	15.4	84.6	0.217	0.571	0.534	0.493	8	11	10	9	1	2
Germany	DE	22.7	77.3	0.232	0.636	0.591	0.540	10	9	7	7	2	2
Greece	EL	43.2	56.8	0.349	0.434	0.322	0.096	24	19	20	23	-1	-4
Hungary	HU	14.8	85.2	0.188	0.377	0.339	0.301	4	20	19	18	1	2
Ireland	IE	16.1	83.9	0.268	0.642	0.568	0.443	17	7	9	10	-2	-3
Italy	IT	51.1	48.9	0.240	0.496	0.456	0.403	11	15	15	15	0	0
Latvia	LV	86.2	13.8	0.391	0.274			25					
Lithuania	LT	31.3	68.7	0.335	0.453	0.374	0.299	22	18	18	19	0	-1
Luxembourg	LU	19.7	80.3	0.270	0.643	0.579	0.496	19	6	8	8	-2	-2
Malta	MT	41.6	58.4	0.317	0.458	0.384	0.308	21	17	17	17	0	0
Netherlands	NL	21.4	78.6	0.219	0.701	0.666	0.622	9	4	5	4	-1	0
Poland	PL	4.7	95.3	0.156	0.327	0.293	0.260	1	23	23	21	0	2
Portugal	PT	52.4	47.6	0.259	0.464			15					
Romania	RO	83.0	17.0	0.514	0.175			27					
Slovakia	SK	34.1	65.9	0.193	0.348	0.309	0.276	5	22	21	20	1	2
Slovenia	SI	39.9	60.1	0.215	0.506	0.474	0.431	7	13	13	11	0	2
Spain	ES	47.3	52.7	0.261	0.480	0.443	0.408	16	16	16	14	0	2
Sweden	SE	21.8	78.2	0.256	0.735	0.691	0.633	14	1	2	3	-1	-2

Source: European Commission (2022). author's processing.
Note: Colour classification of country groups (see under colouring in the first column): yellow = emerging innovators, white = moderate innovators, light green = strong innovators, dark green = innovation leaders

A balance among the innovation sub-dimensions is typical for *Strong innovators*. Variability is concentrated within sub-dimensions (in Investment for Austria, France, Germany Ireland and Cyprus; in Impacts for Luxembourg). In the case of *Moderate innovators*, between-group variability dominates for Italy and Portugal; relatively balanced values among sub-dimensions and higher within-group variability were observed for the Czech Republic (especially in Innovation activities), Estonia (Investment), Greece (Innovation activities), Lithuania (Investment), Malta (Innovation activities), Slovenia (Investment) and Spain (Impacts). In the case of *Emerging innovators*, inter-group variability tends to be more significant for the countries with the lowest innovation performance according to the original SII (Bulgaria, Croatia, Romania). Slovakia (in Impacts), Hungary (in Impacts) and Poland (in Innovation activities) have more balanced innovation performance across sub-dimensions (and higher intra-group variability).

Conclusion

The main aim of this paper is to compare the official ranking of the EU countries in the latest EIS 2022 (SII is the result of using linear aggregation, i.e. arithmetic mean) with the ranking obtained by using alternative methods of final aggregation (geoSII is the result of using the geometric mean, harmSII is the result of using the harmonic mean). The calculation of the arithmetic mean indicates a constant compensability among dimensions, while in alternative aggregations the compensability is lower for composite indicators with low values. In terms of policy (if compensability is allowed), a country with low scores on one indicator will need much higher scores on the others to improve its ranking. The variance decomposition (intra- and inter-group variability) allows to identify the source of the trade-off for individual countries (between or within sub-dimensions); the s.d. within sub-dimensions is a predictor of the change in a country's ranking when an alternative aggregation method is used. ***Innovation leaders*** (5 countries) showed a deterioration in the ranking of Finland (down one position in geoSII and four positions in harmSII), Sweden (down one position in geoSII and two positions in harmSII) and the Netherlands (down one position in geoSII). In the case of Finland, this is due to high within-group variability in the Investment sub-dimension (the second highest variability in the whole sample of countries), while in the case of Sweden, the dominant reason is within-group variability in the Innovation Activities and Investment sub-dimensions. The worse position of the Netherlands can be explained by the penalty of relatively high s.d. in the Investment sub-dimension. The ranking of three ***strong innovators*** (6 countries) has deteriorated - Cyprus (down 2 ranks according to geoSII and 6 ranks according to harmSII), Ireland (down 2 ranks according to geoSII and 3 ranks according to harmSII) and Luxembourg (down 2 ranks according to both alternative methods). In the case of Cyprus, this is due to high within-group variability in the sub-dimensions of Investment, Innovation Activities and Framework Conditions (the third, second and third highest variability in the whole sample of countries), while for Ireland the dominant cause is within-group variability in Innovation Activities and Investment. Luxembourg's worse position can be explained by the penalty for relatively high s.d. in the sub-dimensions of Impact and Investment. Only two ***moderate innovators*** (9 countries in total) have declined in the ranking, namely Greece (down one position in geoSII and 4 positions in harmSII) and Lithuania (down one position in harmSII). In Greece, this is due to high intra-group variability in the sub-dimensions of Innovation Activities and Investment. Lithuania's worse position can be explained by the penalty of a relatively high trade-off within the sub-dimensions Investment and Framework Conditions. For ***Emerging innovators*** (7 countries in total, four countries in the restricted sample[2]), Croatia's ranking has dropped (by one position in geoSII I harmSII). The worse ranking can be explained by the penalisation of relatively high s.d. within the sub-dimensions Investments and Innovation activities.

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[2] In the calculation of geoSII and harmSII it was necessary to exclude Bulgaria, Latvia and Romania due to the lowest values in the input data, i.e. zero values for some variables after normalisation of these input data.

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