IMPACT OF ALTERNATIVE AGGREGATION METHOD ON RESULTS OF THE EU COUNTRIES IN SII (SUMMARY INNOVATION INDEX)

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Abstract

Innovation activities are a prerequisite for long-term competitiveness in the present dynamic world. As innovation performance is a multidimensional phenomenon, composite indices comparing innovation performance in the different samples of countries are used to measure this complex phenomenon. The Summary Innovation Index (SII), the composite indicator of innovation performance discussed in this paper, is accepted by policymakers and other authorities for its ability to integrate different variables describing the positive and negative aspects of countries' innovation performance. The explanatory power of this international ranking is strongly influenced by the choices made during the construction of the composite index (CI). In every composite indicator analysis, the final index is the result of several steps: the choice of a framework (usually driven by theoretical models and experts' opinions), indicators included, the normalisation method, the weighting scheme of individual indicators and sub-indicators, and final aggregation method. The purpose of this paper is to examine how the ranking of the EU countries is changed when the alternative aggregation method (geometric mean) is used. This attitude enables us to reduce the methodological problem of compensability among the sub-indicators. The second objective of this paper is to identify the strengths and weaknesses of the current innovation performance of the Czech Republic.

Key words: composite indicator, European Innovation Scoreboard, innovation performance, Summary Innovation Index

JEL Code: O3, O1, I2

Introduction

Today, the role of innovation as a carrier of competitive advantage and a prerequisite for long-term and sustainable economic growth is emphasised; innovation is also an important part of value-added creation in individual sectors. Innovation is a very complex and difficult-to-measure phenomenon and there is no clear consensus on the indicators that should be used. The concept of innovation and the methods for measuring are widely discussed for decades. Initially, individual indicators derived from national statistics were used, but since the 1990s aggregated variables in the form of composite indicators have become more widely used. Composite indicators are preferred by policymakers who want to have a quick and comparative overview of the innovation performances of different countries. The Summary Innovation Index (SII) published annually by European Commission in the European Innovation Scoreboard (EIS) is accepted for its ability to integrate different variables describing countries' innovation performance and identify the advantages and disadvantages of national innovation systems in international comparison.

The CI construction is a relatively complicated process 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, choice of weighting system (i.e. decision about the aggregation method). The specific choices made during the CI construction have a key impact on the explanatory power of the final CI.

1 Literature review

1.1 Some problematic aspects of the CI construction

An increasing interest in applying composite indicators (CI) is observed in a wide variety of research areas. This seemingly simple method of presenting complex phenomena has methodological shortcomings which distort the explanatory power of the final indicator. The main pros and cons of using composite indicators are widely debated. The literature review concerning the CI methodological framework is provided, e.g. by Greco et al. (2019), and the partial steps during the CI building are analysed, e.g. by OECD (2008). CIs are considered biased, inconsistent, and thus problematic e.g. by Greco et al. (2019). Therefore critical research papers concerning their controversial methodological aspects have been written (Paruolo et al., 2013; Olczyk et al., 2022). The main critical arguments against CIs are the following: 1) the subjective selection of variables (OECD, 2008); 2) the aggregation process (the elementary methods – e.g. the Simple Additive Weighting (SAW) and the Weighted Product (WP) are usually used – see e.g. Becker et al., 2017; Rogge, 2018); 3) weighting is often arbitrary (Cinelli et al., 2021); 4) measurement of a complex and elusive concept is questionable (Kuc-Czarnecka et al., 2020).

Respecting our aim, we focus on the brief discussion of the elementary methods, and the geometrical mean as the method for final aggregation. The elementary methods suppose that the global performance is calculated as the weighted sum of its values for each criterion. E.g. El Gibari et al. (2018) point out that this attitude to aggregation enables total compensation among the different criteria in the case of the SAW method and partial compensation in the WP method. This way of the CI construction presupposes that the weights attached to the different variables 1) add up to one and 2) reflect the importance of the variables. As Kuc-Czarnecka et al. (2020) emphasise, both assumptions mentioned above are highly questionable.

Paruolo et al. (2013) and Olczyk et al. (2022) show that the real importance of variables in the CI may considerably deviate from its weights. These authors argue that different variances and correlations among variables prevent the weights from corresponding to the variables' importance and propose using measures drawn from the global sensitivity analysis (the Pearson correlation ratio)[1].

E.g. Rogge (2018) alerts to the distortion of final results caused by linear aggregation (this method is used in the SII). In his view, the geometrical mean is considered a better method of final aggregation. The reduction in the level of substitutability (the rate of compensation) among dimensions is an important advantage of the geometric mean. Moreover, an arithmetic weighted average does not penalise countries for variability among sub-indicators. (Rogge, 2018)

Bowen and Moesen (2011) show another problematic aspect of the linear aggregation: uniform application of weights may incorrectly penalise some countries and favour other countries so that the final CI and the countries' ranking are biased.

1.2 Some problematic aspects of measuring innovation performance

Paas and Poltimae (2012) show that some measuring problems may occur by elaborating composite indicators of the national innovation performance e.g. the inability to sufficiently capture the quality of human capital, the small economy effect (i.e. high dependence on single enterprises of a sector), data availability issues etc. The measurement results may also be biased by some self-reporting indicators. Paas and Poltimae (2012) compared the EIS and the factor analysis results and obtained confirmation that the composite results for small countries are

[1] The *Pearson correlation ratio* is a variance-based measure which accounts for (possibly nonlinear) dependence between input variables and the composite indicator (see e.g. Paruolo et al., 2013)

sensitive to the self-reporting indicator of the CIS that reflects the role of non-R&D innovations in the national innovation performance.

The results of critical insights of Bielińska-Dusza and Hamerska (2021) on the SII construction can be summarised as follows:

1) EIS methodology is not entirely consistent with the theoretical indications (It is not known what indications and rules determined the selection of specific indicators and whether they are a determinant of or capture the essence of what can be called innovation.)
2) the indicators adopted in the methodology constitute only a certain part of innovative activity
3) a large number of indicators can cause difficulties in determining mutual dependence and clear correlations between the variables, thus increasing the complexity and lowering the readability of the ranking
4) the change in the methodology of preparing reports over the years makes it impossible to compare the results, due to data corrections (Bielińska-Dusza and Hamerska, 2021)

Considering the aforementioned debatable aspects of the construction of CIs and the measurement of innovation performance, it is logical that papers responding to the imperfections of the present CI's methodology are produced. In this paper, our next steps are the following: 1) a brief description of the EIS methodology; 2) an explanation of our approach to working with the data; 3) a comparison of our results obtained by a different aggregation method with those obtained by the original methodology.

2 EIS methodology and "N1" innovator

In the European Innovation Scoreboard (the EIS), innovation indicators are grouped into two main categories: innovation input and output. Innovation input indicators aim to capture the effects of R&D activities, research systems, business investment and collaboration between innovation organisations, especially SMEs, while innovation output indicators focus on the effects of activities in the areas of human resources, intellectual assets, sales and employment impacts (Hollanders et al., 2021).

The EIS differentiates four areas and twelve dimensions of innovation, to which detailed criteria are assigned. Altogether, the last ranking (the EIS 2021) consists of 32 indicators, which are obtained from different sources (e.g. Eurostat, the Scopus database, Community Innovation Survey, Patent data from the OECD, …). Each main group includes an equal number of indicators and has equal weight (25 %) in the Summary Innovation Index (the SII). Every indicator in the SII has the same weight (1/32, i.e. 3, 125 %).

Framework conditions deal with the main drivers of innovation performance external to the firm and differentiate between three innovation dimensions: human resources, attractive research systems, and digitalisation (the number of indicators is given in brackets). Human resources (3) measures the availability of a high-skilled and educated workforce. Attractive research systems (3) measure the international competitiveness of the science base. Digitalisation (2) measures the level of digital technologies and digital skills.

Investments monitor investments made in both the public and business sectors and differentiate between three innovation dimensions (the number of indicators is given in brackets): Finance and support (3), Firm investments (3), and Use of information technologies (2).

Innovation activities capture different aspects of innovation in the business sector and differentiate between three innovation dimensions: Innovators (2), Linkages (3), and Intellectual Assets (3).

Impacts capture the effects of enterprises' innovation activities and differentiate between three innovation dimensions: Employment impacts (2), Sales impacts (3), and Environmental sustainability (3).

According to the EIS assessments, the EU member states are divided into four country groups: 1) innovation leaders, 2) innovation followers, 3) moderate innovators, and 4) catching-up countries. Countries with innovation performance above the EU27 average are in the innovation leaders' and followers' groups, and those with innovation performance below the EU27 average are in the moderate innovators and catching-up countries groups. A brief overview of the methodology is available in Table 1. The first and the second column show the structure of the SII and the nominal importance of dimensions (the weights). Due to the different number of indicators inside dimensions, the nominal weights for dimensions vary, while the weights for individual indicators are equal (1/32 = 3,125 %). The column "best value" and the column "country (best value)" enables us to identify the hypothetical country "N1" and calculate the final value of the CI for this best innovator. The individual member states' relative performance was calculated by comparing their values with the best country (= 100) every year. Table 1 shows the average results for the 2014-2021 reference period. Therefore, a value of 100 for the top country means that the country was the leader in the given dimension in all years (2014-21).

Tab. 1: SII dimensions and "N1" innovator

Areas of innovation (number of indicators/nominal weight, %)	Dimensions (dimension's nominal weight, %)	The best value	Country (the best value) = parts of „N1“
A. Framework conditions (8/25) *The best value: Denmark (mean)* *Denmark (geomean)*	1. Human resources (9,375)	100.0	Sweden
	2. Attractive research systems (9,375)	98.0	Luxembourg
	3. Digitalisation (6,25)	100.0	Denmark
B. Investments (8/25) *The best value: Sweden (mean)* *Sweden (geomean)*	4. Finance and support (9,375)	99.9	France
	5. Firm investments (9,375)	98.1	Germany
	6. Use of inform. technologies (6,25)	100.0	Finland
C. Innovation activities (8/25) *The best value: Finland (mean)* *Finland (geomean)*	7. Innovators (6,25)	84.8	Belgium
	8. Linkages (9,375)	99.0	Denmark
	9. Innovation (9,375)	98.9	Denmark
C. Impacts (8/25) *The best value: Ireland (mean)* *Germany (geomean)*	10. Employment impacts (6,25)	99.4	Luxembourg
	11. Sales impacts (9,375)	99.6	Ireland
	12. Environ. sustainability (9,375)	96.4	Denmark
Composite indicator	**ASII_2 (mean)**	**96.73**	**CI values for "N1 "**
	GSII_2 (geomean)	**96.57**	

Source: European Commision (2021), author's processing.

3 Aims and methods

The first aim of the paper is to compare the countries' results (ranks) according to the original EIS methodology and alternative attitudes based on different methods of final aggregation. The second objective is to identify the strengths and weaknesses of Czech innovation performance compared to the "N1" innovator. We used the time series 2014-21 for the SII. The countries' final values, ranking in individual dimensions, and the composite indicators (calculated on the level of dimensions) were obtained by counting the countries' average results in the periods mentioned above (the output of this attitude is our indicator ASII). To decrease a distortion caused by the substitution among the dimensions in the ASII, the geometrical mean is applied and the final indicator GSII is obtained. Inspired by the paper of Bowen and Moesen (2011), the final value of the ideal hypothetical innovator (country" N1") was calculated. This country is our benchmark for the EU27 member states. We proceed as follows: 1) we take into account the best result (the value of the country with the best evaluation) in the individual dimensions every year; 2) we recalculate the countries' scores in the individual dimensions (the result of the best country = 100) in every year; 3) the arithmetic mean of recalculated scores in the period

2014-21 enables us to obtain the final results; 4) using the aggregation methods described above (mean or geomean calculated on the level of dimensions), we obtained the final value for this hypothetical country in every year; 5) we calculate the average countries' results in the period 2014-21.

4 Results

Table 2 summarises the results obtained. Firstly, this table offers the average value of the SII dimensions in the period 2014-21 (the ASII_1) and the average value of geometric means which were calculated for every year (the GSII_1); secondly, the country's ranking based on the relative performance (compared to benchmark) is presented. A grey (yellow) hint indicates the country's better (worse) rank when the geometric mean was applied. This final aggregation method led to changes in the ranking of some countries: 1) a one-position drop in the ranking of Austria, Hungary, Poland, Spain, Slovenia, and Slovakia; 2) a one-position improvement for Czechia, Germany, Greece, Estonia, Croatia, Latvia, and Portugal.

Tab. 2: Countries' results and ranking in composite indicators

EU27 (2014-21)	ASII_1	GSII_1	ASII_2	GSII_2	ASII_1	GSII_1	ASII_2	GSII_2
	Arithmetic mean (14-21)*		Relative to „N1"		Country's rank			
Austria (AT)	0.60	0.59	72.93	72.39	7	8	8	8
Belgium (BE)	0.61	0.61	74.91	74.17	6	6	6	6
Bulgaria (BG)	0.22	0.19	26.61	22.91	26	26	26	26
Cyprus (CY)	0.39	0.35	48.00	44.47	18	18	18	18
Czechia (CZ)	0.41	0.40	50.40	49.32	16	15	16	16
Germany (DE)	0.60	0.60	74.38	72.58	8	7	7	7
Denmark (DK)	0.67	0.67	82.68	81.29	2	2	2	2
Estonia (EE)	0.46	0.45	56.92	56.15	12	11	11	11
Greece (EL)	0.34	0.32	42.40	39.56	21	20	20	20
Spain (ES)	0.42	0.39	50.34	47.69	15	17	17	17
Finland (FI)	0.64	0.65	80.41	79.79	3	3	3	3
France (FR)	0.57	0.55	67.94	66.49	10	10	10	10
Croatia (HR)	0.30	0.29	37.74	35.83	23	22	23	22
Hungary (HU)	0.34	0.29	39.19	35.96	20	21	21	21

Ireland (IE)	0.58	0.55	68.96	67.01	9	9	9	9
Italy (IT)	0.42	0.41	52.49	49.52	14	14	14	14
Lithuania (LT)	0.36	0.34	45.27	42.24	19	19	19	19
Luxembourg (LU)	0.62	0.61	77.67	74.58	5	5	4	5
Latvia (LV)	0.25	0.24	31.85	30.08	25	24	25	24
Malta (MT)	0.43	0.41	54.72	51.53	13	13	13	13
Netherlands (NL)	0.62	0.62	76.50	75.12	4	4	5	4
Poland (PL)	0.27	0.22	32.33	27.45	24	25	24	25
Portugal (PT)	0.41	0.40	51.09	49.46	17	16	15	15
Romania (RO)	0.15	0.11	18.00	12.85	27	27	27	27
Sweden (SE)	0.68	0.68	83.32	82.60	1	1	1	1
Slovenia (SI)	0.46	0.45	55.37	54.75	11	12	12	12
Slovakia (SK)	0.32	0.29	38.81	35.18	22	23	22	23

Source: European Commission (2021), author's processing. Note: ASII_1 and GSII_1 values are the arithmetic mean of countries' results in the period 2014-21.

The lower difference between ASII_1 and GSII_1 (ASII_2 and GSII_2) usually indicates more equal values across dimensions and a lower compensability among dimensions when the linear aggregation method (arithmetic mean of dimensions or indicators) is applied. The geometric mean as the final aggregation method reduces the possibility of compensation between better and worse values of the dimensions and therefore rewards the countries with more balanced results on the level of dimensions (and penalised the countries with relatively unbalanced results). In addition, the ranking of countries is influenced by the variability of countries' scores on the dimensions and also by the type of competitive advantage or disadvantage (in the dimension with higher or lower variability). In the case of a competitive advantage/disadvantage in a dimension with more significant differences between countries, we would expect a positive/negative boost to the overall ranking. Analysing the impact of intra-country variability within each dimension on the overall ranking of countries will be our goal in subsequent papers. Table 2 shows that there have been no significant changes in the ranking of countries. This can be explained by the relative homogeneity of EU countries in the assessed areas of innovation performance.

4.2 Czech innovation performance – strengths and weaknesses

When assessing the innovation performance of individual countries, the European Commission compares the performance of a given country in each dimension (indicator) with the EU performance in the last and baseline year (2021 and 2014). However, the average EU innovation performance is also affected by the lower innovation performance of countries that belong to the group of moderate innovators or catching-up countries. In our view, a more appropriate approach to the assessment is to compare the countries that perform best in a given dimension (see "N1" innovator). Table 3 offers a comparison of the Czech Republic and the EU with the best country in each dimension in 2014 and 2021. An increase in the value for the Czech Republic (or the EU) in 2021 compared to 2014 means convergence towards the leader, while a deterioration in the result can be described as divergence. The grey hint indicates the divergence of the EU towards the best country (in 2021 compared to 2014), the yellow hint signifies a similar situation for Czechia.

Tab. 3: Convergence or divergence of Czechia and EU to the „N1“ innovator*[2]

		Human resources	Research systems	Digitalisation	Finance and support	Firm investments	Information technologies	Innovators	Linkages	Intellectual assets	Employment impacts	Sales impacts	Environmental sustainability	SII
2014	EU	48.1	54.0	54.2	63.2	63.9	43.8	61.0	44.6	62.3	58.1	70.9	75.7	69.5
	CZ	38.8	30.7	49.7	58.4	45.9	48.8	57.5	40.0	36.1	48.9	65.5	70.8	58.1
	„N1“	**SE**	**LU**	**DK**	**FR**	**SE**	**FI**	**LU**	**DK**	**DE**	**LU**	**IE**	**DK**	
2021	EU	54.5	54.2	65.4	65.4	69.0	49.1	61.2	54.4	56.7	66.2	81.1	66.6	71.9
	CZ	44.6	40.2	51.9	45.5	54.6	57.7	54.8	43.2	33.8	58.7	79.3	63.9	60.3
	„N1“	**SE**	**LU**	**DK**	**FR**	**DE**	**FI**	**CY**	**CY**	**DK**	**SE**	**DE**	**MT**	

Source: European Commission (2021), author's processing.

The greatest convergence of the Czech Republic to "N1" is evident in the Sales impacts dimension, which can be considered as a Czech competitive advantage. More significant convergence can be observed in dimensions with a low starting level (Research systems) and below-average Czech performance compared to the EU (Employment impacts, Firm investments). The small rate of Czech convergence to the „N1“ innovator in the final SII is connected with a) relatively small improvements in Czechia’s strengths (in the dimension Environmental sustainability with the most significant Czech competitive advantage was identified relative deterioration, i.e. divergence) b) worse performance (or the slower rate of

[2] The best country = 100. “N1“ innovator in 2014 is composed of Denmark (the highest score in Digitalisation, Linkages, Environmental sustainability), Finland (Information technologies), France (Finance and support), Germany (Intellectual assets), Ireland (Sales impacts), Luxembourg (Attractive research systems, Innovators, Employment impacts), and Sweden (Human resources, Firms investments). “N1“ innovator in 2021 is composed of Cyprus (the highest score in: Innovators, Linkages), Denmark (the highest score in Digitalisation, Intellectual assets), Finland (Information technologies), France (Finance and support), Germany (Firm investments, Sales impacts), Luxembourg (Attractive research systems), Malta (Environmental sustainability) and Sweden (Human resources, Employment impacts).

improvement) compared to other EU countries in other dimensions. Czechia's strengths in the EIS 2021 were in the Use of information technologies, Sales impacts and Environmental sustainability. „The top-3 indicators include Enterprises providing ICT training, Exports of medium and high-tech goods, and Air emissions by fine particulate matter. The recent increase in innovation performance between 2020 and 2021 is due to strong performance increases in several indicators using innovation survey data, Broadband penetration, and Venture capital. Czechia has an above-average share of In-house product innovators with market novelties and is showing close to average scores on the Climate change-related indicators". (Hollanders et al., 2021) The divergence from the "N1" innovator is evident in dimensions with the relative Czechia's disadvantages, e.g. Intellectual assets and Finance and support, the relatively lower rate of improvement is observed in Environmental sustainability and Intellectual assets.

Conclusion

The explanatory power of the SII and other composite indicators is significantly influenced by the choices made during their construction. In this paper, we used an alternative method of final SII aggregation-the geometric mean of the 12 dimensions of innovation performance-in order to reduce the substitution of worse results by better ones that are typical of the commonly used linear aggregation (i.e., the arithmetic mean of indicators or dimensions). The alternative aggregation method led to the small changes in the ranking of some countries: 1) a one-position drop in the ranking of Austria, Hungary, Poland, Spain, Slovenia, and Slovakia; 2) a one-position improvement for Czechia, Germany, Greece, Estonia, Croatia, Latvia, and Portugal. The insignificant changes in ranking can be explained by the relatively small and homogenous sample (the EU countries). Czechia's strengths in the EIS 2021 were in the Use of information technologies, Sales impacts and Environmental sustainability. The moderate rate of Czech convergence to the „N1" innovator is due to both (1) relatively small improvements in Czechia's strengths and (2) worse performance (or the slower rate of improvement) in other dimensions compared to other EU countries.

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