INNOVATION OUTPUT INDICATOR REVISITED: A MORE BALANCED APPROACH TO MEASURING INNOVATION PERFORMANCE

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Abstract

The Innovation Output Indicator (IOI) is a composite metric published by the European Commission since 2013. The IOI serves as a tool for assessing a country's ability to generate economic benefits from innovation by tracking how effectively innovative ideas reach the market, foster the creation of knowledge-intensive jobs, and enhance the country's technological capability. In the latest edition (2023), the IOI score is calculated as the arithmetic average of the following components: Intellectual Property (IP), knowledge-intensive activities in business industries (KIABI), domestic technology capacity (TECH CAP), and the share of innovation-active firms compared to the total number of firms (ENT). Due to the use of the arithmetic mean for aggregation, all indicators and pillars of the IOI are equally weighted within the composite index. However, this linear aggregation method has a potential downside: it allows for the substitution of poorer values with better ones. This paper has three objectives: 1) Examine how country rankings change when the final aggregation method is switched from arithmetic to a geometric mean, 2) Analyse how the classification of countries into **innovation leaders, strong innovators, moderate innovators,** and **emerging innovators**—as used in the European Innovation Scoreboard (EIS)—is affected when applying a more balanced approach of the final aggregation (geometric mean), and 3) Assess the contributions of each IOI component to the final scores of different country groups to identify their strengths and weaknesses.

Key words: Innovation Output Indicator, European Innovation Scoreboard, geometric mean, innovation performance

JEL Code: O10, O30, O39

Introduction

Innovation performance is broadly defined as a country's ability to generate and exploit innovation. It is an important indicator of economic competitiveness and is therefore the subject of international comparisons. Countries with higher innovation performance tend to experience sustained economic growth and greater prosperity and perform better in international rankings. Innovation directly stimulates the development of new technologies, products, and services, enabling firms to improve performance, create skilled jobs, and expand. The recent increase in the importance of innovation is linked to digitalisation, climate change awareness and ongoing geopolitical uncertainty. Composite indicators are favoured by policymakers, who require relatively simple yet comprehensive tools with which to evaluate national innovation performance. Ideally, a composite indicator of innovation performance would guide the design of adequate economic policy. This paper aims to compare the results of the original IOI ranking with those obtained using the alternative final aggregation method (geometric mean), and to identify the competitive advantages and disadvantages of innovation leaders, as well as strong, moderate and emerging innovators.

1 Literature review and methodology

1.1 Measuring innovation performance using composite indicators - a brief critical assessment

When evaluating the results of composite indicators, it is important to consider how they are constructed. As Greco et al. (2018) emphasise, the validity of a composite indicator (CI) is intrinsically linked to its construction. Consequently, these measures should be interpreted with extreme caution, especially when important conclusions are to be drawn from them (e.g., by policymakers, the media, or the public). CIs are constructed based on several key choices: the choice of framework (usually determined by theoretical models and expert opinion); the choice of appropriate variables; the choice of normalisation method; and the choice of weighting system (i.e. the aggregation method). The key findings of articles critically evaluating the measurement of innovation performance using CIs are mainly related to the partial steps in their construction and can be categorised as follows:

a) Methodological aspects

Many studies (e.g. Greco et al., Edquist et al. and Cherchye et al.) point out that equal or arbitrary weighting of indicators lacks theoretical justification and can distort country rankings. Furthermore, El Gibari et al. (2018) highlight that the arithmetic mean (linear aggregation) enables total compensation among the different criteria.[1] Munda and Nardo (2009) analyse the

[1] Linear aggregation means that:1) the weights attached to the different variables add up to one, and 2) the weights reflect the importance of the variables.

case of aggregation rules in the framework of composite indicators and conclude that the use of non-linear/non-compensatory aggregation rules to construct composite indicators is compulsory for reasons of theoretical consistency when weights with the meaning of importance coefficients are used. 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).

Another methodological aspect is connected with a lack of theoretical grounding. Indicator selection is often not based on a coherent innovation theory, leading to questionable relevance (Greco et al., 2018).

b) Issues of validity and interpretability

A composite indicator is often a mix of indicators assessing assumptions and outcomes. If a composite indicator is a mix of input and output indicators without a clear distinction, it is not possible to interpret what the final score reflects (Edquist et al., 2018)

c) Policy Implications

Comparison of innovation performance through simple scores can lead to suboptimal decisions. Economic policy decisions may be focused on improving scores rather than addressing actual innovation problems (e.g. Bandura, 2008). Corrente et al.(2023) draw attention to the different motivations of different actors in the innovation process. It is reasonable to assume that each actor (university, industry and government) has specific aims and objectives that a single ‘objective’ ranking would not take adequately into account. Consequently, the assessment of a single comprehensive ranking ‘valid for all the actors’ would be quite abstract. (Corrente et al., 2023)

1.2 The IOI methodology – a brief description

The Innovation Output Index (IOI) has been published annually by the European Commission since 2013. The IOI aims to offer an output-focused metric of innovation performance at the country and EU levels. The IOI tries to measure countries' capacity to derive economic benefits from innovation by tracking the extent to which innovative ideas reach the market, create knowledge-intensive jobs, and increase a country's technological capability (JRC, European

Commission, 2024). Compared to the 2023 edition, the 2024 version of the IOI worked with updated data for most of the underlying indicators. It also includes an extension of country coverage to 46 economies[2]. (JRC, European Commission, 2024) Table 1 (and explanatory notes below) provides the following information: a) an overview of the IOI indicators and components, b) an overview of the best and worst performers in the IOI indicators and components for the EU-27 countries (the results are based on the standardised values and the original methodology of final aggregation), c) the results of the variability in each indicator.

Tab. 1: IOI indicators and top performers

IOI components	Indicators *Nominal weight of indicator: 16,66 %*	s.d.	The best value (2024)	The worst value (2024)
A. Intellectual Property (IP) *The best value: Sweden (4.96)* *The worst value: Romania (0.4)*	1TRA_POP	1.38	Malta (5.58)	Hungary(0.54)
	2. PCT_POP	2.43	Sweden (8.1)	Romania (0.09)
B. Knowledge-intensive activities in business industries (KIABI)	3. KIABI	1.87	*Luxembourg (10)*	*Romania (1.5)*
C. Domestic technology capacity (TECH_CAP) *The best value: Germany (6.68)* *The worst value: Lithuania (1.47)*	4. GOOD_VA	1.67	Germany (7.47)	Luxembourg (0.86)
	5. SERV_VA	1.11	Finland (6.5)	Lithuania (1.39)
D. Innovative enterprises (ENT)	6. ENT	2.16	*Greece (8.98)*	*Romania (0.07)*

Explanatory notes: 1) TRA_POP = trademark classes per million population, PCT_POP = patents filed under the patent cooperation treaty per million population, KIABI = knowledge-intensive activities in business industries (measured by the number of persons employed in knowledge-intensive business industries within total employment), TECH_CAP = domestic technology capacity to the country's exports in knowledge-intensive manufacturing and service sectors, GOOD_VA = domestic value-added content of medium-high and high-tech manufacturing exports as a share of total manufacturing exports, SERV_VA = knowledge-intensive service exports as a share of total service exports (SERV_VA), ENT = the share of innovation-active firms on the total number of firms

2) s.d.= variability among the EU countries in the indicator (normalised values)

Source: European Commission (Joint Research Centre), 2024; author's processing.

The greatest variability was found in the PCT-POP indicator (i.e. number of patents), followed by the ENT indicator (i.e. representation of innovative firms). A country's excellent performance in these indicators gives it a relatively significant competitive advantage, as it has a significant impact on the overall performance and final ranking. The top-ranked countries showcase relatively balanced achievements across the different dimensions considered in the IOI.

[2] EU Member States and selected benchmark countries, which include members of the EFTA, OECD and BRICS groups as well as additional emerging economies. The latest data used in this report refer to 2022, but for some indicators, the latest available data refer to 2020 or earlier. This version also includes, for the first time, an analysis of countries' innovation output performance change over the last decade and provides useful insights regarding the countries that define and shift the frontier of innovation output possibilities over time. (JRC, European Commission, 2024)

1.3 Aims and Methods

The paper reflects critical arguments concerning the construction of composite indicators, in particular the choice of the final aggregation of sub-indicators. The chosen method of final aggregation is the geometric mean, which allows only partial compensation of worse values with better ones and prefers excellent and balanced results in sub-indicators. Based on the final geoIOI values, a new ranking of EU-27 countries is created, and the distribution of countries among innovation leaders, strong, moderate, and emerging innovators is changed. The calculation of the indicator contributions to the overall score *(contribution of indicator = (indicator weight x indicator score) x 100/ IOI score*) enables identifying the strengths and weaknesses of the innovation performance of individual countries as well as of groups of innovators.

2 Results

Table 2 allows a comparison of the EU-27 countries based on: a) the score of the original IOI (final aggregation by arithmetic mean) and b) the geoIOI (final aggregation by geometric mean). The countrïes' ranking is calculated in both cases. The last column describes the change in the ranking, the colour shading indicates the classification of the country in the group of innovators (blue - innovation leaders with a performance above 125 % of the EU-27 average, pink - strong innovators with an above average innovation performance between 100-125 %, green - moderate innovators with a performance between 75-100 % of the EU-27 average, white - emerging innovators). Table 3 provides an overview of the competitive advantages and disadvantages of each country. The colour shading of the cells enables the distinction of groups of innovators in the sub-indicators. For example, the Czech Republic has an above-average performance (and competitive advantage) in the GOOD_VA and ENT indicators, which places it among the strong innovators (see pink cell shading). Below-average performance in PCT_POP indicates the Czech Republic's competitive disadvantage and its classification among emerging innovators.

Tab. 2: The original IOI and the geoIOI – results and ranking of EU countries

country	IOI	group	IOI rank	s.d.	s.d.rank	geoIOI	group	geoIOI rank	change of rank
Austria	4.50	strong	10	1.56	7	4.28	strong	7	3
Belgium	4.68	strong	8	2.56	24	4.00	strong	9	-1
Bulgaria	2.34	emerging	24	1.34	3	1.71	emerging	25	-1

Croatia	2.92	moderate	20	2.44	22	1.75	emerging	23	-3
Cyprus	4.43	strong	11	2.77	25	3.11	moderate	13	-2
Czech Republic	3.56	moderate	16	2.16	16	2.79	moderate	16	0
Denmark	4.92	leader	5	2.26	18	4.28	strong	8	-3
Estonia	3.68	moderate	14	2.39	20	2.97	moderate	15	-1
Finland	5.47	leader	3	2.41	21	4.78	leader	4	-1
France	4.62	strong	9	1.49	5	4.40	strong	6	3
Germany	5.79	leader	2	1.99	13	5.47	leader	2	0
Greece	3.22	moderate	17	3.28	27	1.84	emerging	21	-4
Hungary	2.62	emerging	21	1.58	8	1.99	emerging	19	2
Ireland	5.21	leader	4	1.85	11	4.94	leader	3	1
Italy	3.71	moderate	13	1.97	12	3.25	moderate	12	1
Latvia	2.22	emerging	26	1.26	1	1.82	emerging	22	4
Lithuania	2.43	emerging	23	2.17	17	1.68	emerging	26	-3
Luxembourg	4.84	leader	6	3.03	26	3.87	strong	10	-4
Malta	4.20	strong	12	2.09	15	3.44	moderate	11	1
Netherlands	4.77	leader	7	1.79	10	4.45	leader	5	2
Poland	2.31	emerging	25	1.37	4	1.73	emerging	24	1
Portugal	3.16	moderate	18	1.73	9	2.61	emerging	18	0
Romania	2.17	emerging	27	2.55	23	0.76	emerging	27	0
Slovakia	2.51	emerging	22	1.33	2	1.95	emerging	20	2
Slovenia	3.59	moderate	15	2.08	14	3.05	moderate	14	1
Spain	3.04	moderate	19	1.50	6	2.64	emerging	17	2
Sweden	6.10	leader	1	2.38	19	5.50	leader	1	0

Source: European Commission (Joint Research Centre), 2024; author's processing

According to the original IOI, Sweden and Germany are the best performers in the EU and are followed by Finland, and Ireland. Germany outperforms the other EU countries in the domestic value-added content of its knowledge-intensive manufacturing exports (GOOD_VA), whereas Sweden is very strong in terms of IP applications (PCT_POP). Conversely, Romania, Latvia and Poland reported the lowest performance among EU countries. Table 2 shows that countries with high and balanced scores in all innovation performance indicators remain leaders in the geoIOI. Greece and Luxembourg recorded the largest deterioration in innovation performance and the largest ranking drop (by four places), respectively. Both countries show uneven scores (high variability) in the sub-indicators. Greece's competitive disadvantage is in Intellectual Property (24th place in PCT_POP) and trademarks (25th place in TRA_POP). Luxembourg's competitive disadvantage is domestic technological capacity (see the last place in GOOD_VA and the 21st place in SERV_VA). The final positions of Croatia (due to low scores in the Intellectual Property indicators PCT_POP and TRA_POP), Denmark (competitive disadvantage in SERV_VA and TRA_POP), and Lithuania (due to below-average domestic technological capacity) have deteriorated by three places. The alternative aggregation method yields the largest ranking improvement for Latvia (four places), which is due to the lowest variability among sub-indicators. The excellence in PCT_POP in the case of Austria and the relatively high scores in GOOD_VA and TRA_POP in the case of France explain the three-place improvement in the rank of Austria and France. Table 2 also shows what changes in the innovator groups occurred as a result of the final aggregation using the geometric mean. The rationale for these changes can be found in Table 3, which maps the competitive advantages and disadvantages of each country.

Tab. 3: IOI sub-indicators - results and ranking of the EU-27 countries

	GOOD_va	rank_GOOD	SERV_va	rank_SERV	Patents	rank_PATENT	Trademarks	rank_TRADE	ENT	rank_ENT	KIABI	rank_KIABI
Austria	3.69	15	4.3	12	4.58	6	2.46	9	7.17	8	4.82	11
Belgium	4.08	12	5.26	4	3.1	8	1.26	21	8.8	2	5.58	7
Bulgaria	2.42	21	3.28	19	0.21	26	1.31	18	3.74	22	3.05	24
Croatia	2.36	22	5.02	5	0.22	25	0.59	26	6.43	15	2.92	25
Cyprus	4.05	13	5.01	6	0.33	21	2.56	7	8	5	6.64	6
Czech Republic	4.74	7	3.5	18	0.56	18	1.9	11	6.72	11	3.94	17
Denmark	6.35	2	3.21	22	6.87	2	1.3	19	6.84	9	4.96	10
Estonia	2.03	23	3.73	15	0.81	14	3.22	5	7.77	7	4.51	14
Finland	4.47	10	6.5	1	6.59	3	1.34	17	8.41	4	5.53	8
France	6.11	4	4.33	10	2.54	10	3.53	4	6.42	16	4.78	12
Germany	7.47	1	5.9	2	5.49	4	2.92	6	8.44	3	4.51	13
Greece	1.22	26	4.65	8	0.3	24	0.74	25	8.98	1	3.41	22
Hungary	3.6	16	3.69	16	0.68	15	0.54	27	3.24	25	3.98	16
Ireland	4.53	8	4.71	7	2.78	9	4.52	3	6.82	10	7.92	2
Italy	5.16	6	2.9	25	1.69	11	1.68	13	6.55	13	4.25	15
Latvia	1.85	24	3.26	20	0.53	19	1.02	22	3.14	26	3.5	21
Lithuania	1.54	25	1.39	27	0.35	20	1.27	20	6.16	17	3.85	18
Luxembourg	0.86	27	3.22	21	4.35	7	5.45	2	5.14	19	10	1
Malta	3.48	17	4.23	13	0.66	16	5.58	1	4.45	20	6.81	5
Netherlands	4.05	14	3.86	14	5.06	5	2.17	10	6.56	12	6.9	4
Poland	3.26	18	3.12	23	0.33	22	0.82	23	3.56	23	2.74	26

Portugal	2.73	20	3.58	17	0.6	17	2.55	8	5.89	18	3.63	20
Romania	6.26	3	4.34	9	0.09	27	0.75	24	0.07	27	1.5	27
Slovakia	3.2	19	3.1	24	0.32	23	1.45	15	3.8	21	3.19	23
Slovenia	4.44	11	2.48	26	1.35	12	1.62	14	6.48	14	5.18	9
Spain	4.49	9	4.32	11	1.03	13	1.35	16	3.34	24	3.72	19
Sweden	5.66	5	5.48	3	8.1	1	1.83	12	7.92	6	7.61	3
arithmetic mean	***3.86***		***4.01***		***2.20***		***2.06***		***5.96***		***4.79***	
median	***4.05***		***3.86***		***0.81***		***1.62***		***6.48***		***4.51***	
s.d.	***1.67***		***1.11***		***2.43***		***1.38***		***2.16***		***1.87***	

Source European Commission (Joint Research Centre), 2024; author's processing

As a result of the geometric mean penalty, Denmark and Luxembourg leave the group of innovation leaders - Denmark for a below-average performance in the SERV_VA indicator, Luxembourg due to large differences among the values of the sub-indicators and a below-average performance in the GOOD_VA indicator of domestic technological capacity (less than 75% of the EU-27 average). For both countries, a deterioration in the ranking has been found (see text above). Cyprus' move to moderate innovators is explained by its unbalanced performance and the competitive disadvantage in patents (PCT_POP). In the case of Malta, the competitive disadvantage is found in the ranking in the PCT_POP and ENT indicators. The final aggregation method penalises countries with unbalanced scores, which is why Croatia, Greece, Portugal and Spain move from moderate innovators to emerging innovators. Differences in scores and groups are driven by the IP performance, particularly the number of patents (PCT_POP). The highest standard deviation indicates a significant competitive advantage of the countries with excellent performance, the relatively high difference between the median and the arithmetic mean is related precisely to the excellent performance of the innovation leaders (Sweden, Finland and Denmark) and the low performance of most of the other EU-27 countries (16 countries have below average scores).

Tab. 4: Contributions of sub-indicators to the final score (EU-27 countries)

	GOOD_va	SERV_va	Patents	Trademarks	ENT	KIABI
Denmark	21.5	10.9	23.3	4.4	23.2	16.8
Finland	13.6	19.8	20.1	4.1	25.6	16.8
Germany	21.5	17.0	15.8	8.4	24.3	13.0
Ireland	14.5	15.1	8.9	14.5	21.8	25.3
Luxembourg	3.0	11.1	15.0	18.8	17.7	34.5
Netherlands	14.2	13.5	17.7	7.6	22.9	24.1

	GOOD_va	SERV_va	Patents	Trademarks	ENT	KIABI
Sweden	15.5	15.0	22.1	5.0	21.6	20.8
av contribution	***14.8***	***14.6***	***17.6***	***9.0***	***22.4***	***21.6***
Austria	13.7	15.9	17.0	9.1	26.5	17.8
Belgium	14.5	18.7	11.0	4.5	31.3	19.9
Cyprus	15.2	18.8	1.2	9.6	30.1	25.0
France	22.0	15.6	9.2	12.7	23.2	17.3
Malta	13.8	16.8	2.6	22.1	17.7	27.0
av contribution	***15.8***	***17.2***	***8.2***	***11.6***	***25.8***	***21.4***
Croatia	13.5	28.6	1.3	3.4	36.7	16.6
Czech Republic	22.2	16.4	2.6	8.9	31.5	18.4
Estonia	9.2	16.9	3.7	14.6	35.2	20.4
Greece	6.3	24.1	1.6	3.8	46.5	17.7
Italy	23.2	13.0	7.6	7.6	29.5	19.1
Portugal	14.4	18.9	3.2	13.4	31.0	19.1
Slovenia	20.6	11.5	6.3	7.5	30.1	24.0
Spain	24.6	23.7	5.6	7.4	18.3	20.4
Av contribution	***16.8***	***19.1***	***4.0***	***8.3***	***32.4***	***19.5***
Bulgaria	17.3	23.4	1.5	9.4	26.7	21.8
Hungary	22.9	23.5	4.3	3.4	20.6	25.3
Latvia	13.9	24.5	4.0	7.7	23.6	26.3
Lithuania	10.6	9.5	2.4	8.7	42.3	26.4
Poland	23.6	22.6	2.4	5.9	25.7	19.8
Romania	48.1	33.4	0.7	5.8	0.5	11.5
Slovakia	21.2	20.6	2.1	9.6	25.2	21.2
Av contribution	***22.5***	***22.5***	***2.5***	***7.2***	***23.5***	***21.8***

Source: European Commission (Joint Research Centre), 2024; author's processing

Table 4 shows the following: a) the contributions of the sub-indicators to the final IOI for each country, b) the average contribution of the indicator for innovation leaders, strong innovators, moderate innovators and emerging innovators. Innovation leaders have relatively balanced contributions of sub-indicators with a competitive advantage in the intellectual property component (PCT_POP and TRA-POP) and knowledge-intensive activities in business industries (KIABI). The competitive advantage of strong innovators is given by the number of innovative enterprises (ENT) and knowledge-intensive activities in business industries (KIABI). For moderate innovators, the final score is most influenced by the indicators of domestic technological capacity (GOOD_VA and SERV_VA), while the number of innovative enterprises (ENT) is the most significant competitive advantage across all country groups and sub-indicators. The innovation performance of emerging innovators is mainly driven by domestic technological capacity (contributing about 45% to the final score) and the number of innovative enterprises (especially in Lithuania, Slovakia, Bulgaria and Poland).

Conclusion

The primary objective of this paper is to compare the official ranking of EU countries in the latest IOI 2024 (IOI is the result of using linear aggregation, i.e., arithmetic mean) with the ranking obtained by using an alternative method of final aggregation - the geoIOI, which is the result of using the geometric mean. The paper focuses on the impact of the alternative method on the scores and rankings of the EU-27 countries. The second objective is to map the influence of the geometric mean on the distribution of countries by innovation performance. The third objective is to identify the competitive advantages and disadvantages of individual countries and groups of innovators. The geometric mean allows only a partial substitution of worse results for better ones and penalises countries with unbalanced and low results in sub-indicators. Countries with high and balanced scores in all indicators (Finland, Germany, Ireland, Netherlands, Sweden) continued to be innovation leaders. Greece and Luxembourg recorded the largest deterioration (by four places), while Latvia improved the most (by four places). The reason some countries have moved into the group of worse performers is that the values in the sub-indicators are imbalanced. The contributions of individual indicators to the overall score are the most balanced in the innovation leaders group. Their competitive advantage was identified in the intellectual property indicators. Differences among leaders and other countries in patents (PCT_POP) are crucial for excellent performance. The competitive advantage of strong innovators is grounded in the number of innovative enterprises (ENT). For moderate innovators and emerging innovators, domestic technological capacity and the number of innovative enterprises are crucial for innovative performance.

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