Modeling of the Integral Index of Investment and Innovation Security

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Abstract

The study is devoted to solving the theoretical and applied problem of assessment of the investment and innovation security status of Ukraine based on the modeling of the Integral index of investment and innovation security and on identifying the interrelationships between different indicators characterizing innovation and investment spheres of Ukraine. The Integral (composite) index model was tested based on actual data from Ukraine for the period 2014–2022 using methods of data normalization and determination of characteristic values of the factor variables based on international experience and analysis of national regulatory restrictions for relevant indicators. Integration of factor variables into the Integral index estimates was carried out based on weighting coefficients calculated both based on expert evaluation method and alternative statistical methods: correlation analysis, pairwise correlation between GDP growth rates and every factor variable, as well as the principal component method. It has been proven that when identifying weak associations between indicators of innovative development and GDP dynamics, determining the weights of indicators based on their correlation with GDP growth rates leads to an overestimation of the Integral index of investment and innovation security. The proposed statistical methods for calculating the weighting coefficients of the variables in the model do not lead to distortion of trends in investment and innovation security, and therefore ensure obtaining consistent and, in contrast to the expert evaluation method, unbiased estimates of the status of investment and innovation security of the country. The results obtained are important in the context of solving strategic problems to prevent risks for the investment and innovation security of Ukraine and forming an innovative foundation for the revival of Ukraine's economy.

Keywords

Integral (composite) index; investment and innovation security; statistical weighting methods; expert evaluation; robustness and sensitivity testing.

1. Introduction

Russian aggressive war against Ukraine, complete with cyber-attacks and measles attacks on infrastructure, following the COVID-19 pandemic, has dramatically changed the security situation and—consequently—the approaches to ensuring security in many countries [1]. The European Commission's experts note that the new European strategy for economic security has to guarantee that economic interests and security interests will reinforce each other. In addition, ensuring the country's economic security and improving its' economic sustainability requires increased technological possibilities [2, 3].

NATO Heads of State and Government approved the new NATO strategic concept (in Madrid on June 29, 2022) [4], which is aimed at solving the tasks of state security, defense, crisis management, and crisis prevention. Within the framework of the main objectives of the concept, the universal importance of investment in technological innovation is

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particularly highlighted, considering that new technologies are becoming key areas of both global competition and battlefield success. In OECD countries, national science, technology, and innovation strategies have become the main pillars of post-crisis policies and economic growth strategies [5].

Active use of modern economic growth factors, that ensure the formation of an innovative basis for long-term economic development, is an important prerequisite for the successful post-war recovery of the Ukrainian economy. In the current context of large-scale military aggression, the identification of threats and risks for innovative development of the Ukrainian economy requires improved approaches to assessing the state of investment and innovation security. The latter should be consistent with the implementation of the economic security strategy of Ukraine [6, 7].

Implementation of the Economic Security Strategy of Ukraine for the period up to 2025 (paragraph 27) requires an annual evaluation of the economic security status to identify possible challenges and threats and to use the evaluation results to formulate the main directions and measures of economic policy.

2. Literature Review

Theoretical aspects of the formation of an institutional system as a factor of innovative development, as well as risk factors in the areas of innovation and investment activity and possible threats to economic recovery, are studied in the monograph by Iefymenko, T. [8]. The article by Iefymenko, T., Lovinska, L., & Kucheriava, M. [9] provides suggestions on the establishment of an information and analytical database for strategic decision-making under martial law. The work of K. Brown and co-authors [10] summarizes approaches to identifying factors that can have an adverse impact on investment activity and economic development and substantiates the ways to take them into account when forming country risk indices.

The works of Ukrainian and foreign authors discuss methodological approaches to the selection and prioritization of indicators characterizing the economic security of the state and its components, as well as the development of models for assessing economic security status and calculation of the relevant integral indices [11–15]. Freudenberg, M. [16] focuses on the peculiarities of the application of different methods to the construction of composite indicators.

3. Research Methodology

The state of investment and innovation security is among the important prerequisites for economic growth and enhancing the international competitiveness of countries. This component of economic security acquires particular importance when solving the problems of eliminating the consequences of military aggression and forming an innovative foundation for the post-war economic recovery of Ukraine [17].

Analysis of investment and innovation security as a complex integrated sphere of economic activity requires the use of generalizing characteristics of its status in different periods. As evidenced by widespread international practice, quite often the solution to such problems for various spheres of the economy, society, or the environment is carried out using complex indicators or integral indices that serve as generalizing characteristics of certain processes or phenomena (for example, Sustainable Development Index, Human Development Index, Corruption Perceptions Index, Environmental Sustainability Index).

The Integral index of investment and innovation security, as well as indices for other areas of economic security, is calculated using formula (1) [18]:

$$I = \sum_{j=1}^{n} a_j \ y_j, \qquad (1)$$

where I is an Integral index of investment and innovation security, coefficient, a_j weighting coefficients determining the degree of contribution of the j^{th} indicator of investment and innovation security to the Integral index, $\sum a_j = 1$, n number of indicators of investment and innovation security, y_j normalized value of the j^{th} indicator of investment and innovation security, coefficient, $0 \leq y_j \leq 1$.

Modeling of the Integral index includes the following steps [18]:

- Detection of a set of indicators characterizing the status of investment and innovation security.

- Normalization of investment and innovation security indicators values (y_j) based on the determination of their characteristic values.
- Calculation of the indicators' weighting coefficients (a_j).
- Assessment of the Integral index of investment and innovation security *(I)*.

3.1. Detection of Initial Indicators and Formation of a Set [$x_1, x_2, \ldots, x_n$]

The first step of modeling involves detecting—based on theoretical, substantive considerations, the results of generalizing the experience of different countries and analyzing the multicollinearity of initial indicators—the most informative indicators for characterizing the investment and innovation sphere of Ukraine.

According to the Economic Security Strategy of Ukraine for the period up to 2025, the set of indicators of investment and innovation security includes 7 variables:

- Net increase in foreign direct investment, percent of gross domestic product.
- Gross fixed capital formation, percent of gross domestic product.
- Industrial enterprises that introduced innovations (products and/or technological processes), in the total number of industrial enterprises, percent.
- Innovative industrial products (goods, services) sold in the total amount of industrial products (goods, services) sold, percent.
- Research and development costs (hereinafter referred to as R&D) are funded by the state budget, percent of gross domestic product.
- R&D expenditures in gross domestic product, percent.
- Ukraine's rank in the Global Innovation Index ranking.

At the same time, in our opinion, these indicators will not provide a comprehensive vision of the status and threats of the investment and innovation spheres. Based on the results of the analysis of international innovation indices, we consider it reasonable to supplement the set of investment and innovation security indicators with two variables:

- Loans provided to other non-financial corporations as a share of gross domestic product; given that lending to enterprises is an important prerequisite for increasing their financial capacity and investment and, accordingly, strengthening the investment security of Ukraine.
- The exports-to-imports ratio of the royalties, licensing services, computer and information services, D&D, and services in architectural, engineering, and other technical industries. This indicator characterizes the level of technological independence of the country. Technological dependence, especially on one or two countries of the world, is a serious risk for Ukraine since it leads to increased investment dependence on imports and inhibition of innovative development.

It should also be noted that the indicator "Ukraine's rank in the Global Innovation Index ranking," which is included in the set of indicators of investment and innovation security according to the Economic Security Strategy of Ukraine for the period up to 2025, describes not only the achievements or failures in Ukraine but also in other countries. Accordingly, Ukraine's rank could be improved both due to the achievements in Ukraine and because of the worsening situation in other sample countries. Therefore, further analysis was carried out both with this indicator (i.e., for 9 indicators) and without it (for 8 indicators).

The full list of the set of indicators and their values is shown in Table 1.

Table 1
Indicators of investment and innovation security of Ukraine in 2014–2022 [19]

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
2014	0.60	0.25	12.10	2.50	2.05	14.14	-11.50	45.04	63
2015	0.55	0.21	15.20	1.40	1.99	13.55	4.40	36.01	64
2016	0.48	0.16	16.60	1.00	2.34	15.46	4.34	31.25	56
2017	0.45	0.16	14.30	0.70	2.26	15.78	1.37	24.88	50
2018	0.47	0.17	15.60	0.80	2.32	17.65	3.62	21.71	43
2019	0.43	0.17	13.80	1.30	2.45	17.62	3.91	17.19	47
2020	0.40	0.18	14.90	1.90	2.83	13.37	-0.02	15.85	45
2021	0.29	0.17	5.80	1.25	3.04	13.20	3.66	12.84	49
2022	0.33	0.19	5.00	1.10	5.21	11.61	0.35	13.32	57

Notes:

x_1—R&D expenditures, % of GDP.

x_2—R&D funded by the State budget, % of GDP.

x_3—industrial enterprises that introduced innovations in the total number of industrial enterprises, %.

x_4—innovative industrial products (goods, services) sold in the total amount of industrial products (goods, services) sold, %.

x_5—the exports-to-imports ratio of the royalties, licensing services, computer and information services, D&D, and services in architectural, engineering, and other technical industries.

x_6—gross fixed capital formation, % of GDP.

x_7—foreign direct investment to Ukraine, % of GDP.

x_8—loans provided to other non-financial corporations, % of GDP.

x_9—Ukraine's rank in the Global Innovation Index ranking.

Correlation analysis of a set of 9 indicators (Table 2) shows that the Pearson correlation coefficient exceeds 0.8, which indicates collinearity [20] only between such indicators: R&D expenditures, % of GDP (x_1) and loans provided to other non-financial corporations, % of GDP (x_8), R&D funded by the State budget, % of GDP (x_2) and innovative industrial products (goods, services) sold in total amount of industrial products (goods, services) sold, % (x_4). If a significant pairwise correlation is identified between indicators, that are important and without which the assessment of the security status would be incomplete, they are kept in the set of indicators of investment and innovation security, but further—in particular, on the stage of expert evaluation—they are given less weight (a_j).

Table 2
Multiple correlation matrix of investment and innovation security indicators, 2014–2022

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
x_1	1.00								
x_2	0.59	1.00							
x_3	0.67	-0.12	1.00						
x_4	0.39	0.82	-0.04	1.00					
x_5	-0.7	-0.1	-0.77	-0.2	1.00				
x_6	0.31	-0.4	0.64	-0.4	-0.6	1.00			
x_7	-0.4	-0.8	0.15	-0.8	0.05	0.26	1.00		
x_8	0.93	0.67	0.46	0.45	-0.62	0.08	-0.53	1.00	
x_9	0.53	0.72	-0.11	0.4	-0.02	-0.49	-0.41	0.72	1.00

Source: authors' calculations.

3.2. Determination of the Indicator's Characteristic Values

The detected indicators that characterize the investment and innovation sphere have different units of measurement: % of GDP (x_1, x_2, x_6, x_7, x_8), specific weight or share of the total value (x_3, x_4), and the rank (x_9) (Table 2). Therefore, their aggregation requires a transition to the unified measurement scale, that is, normalization, when a vector of detected indicators [x_1, x_2,..., x_n] is replaced by a vector of normalized values [y_1, y_2,..., y_n] in such a way as to bring them to common scale without distorting differences in value ranges and without loss of information. To normalize indicators for assessing investment and innovation security, characteristic values are used (optimal, satisfactory, unsatisfactory, dangerous, critical), since this makes it possible to identify situations that impede the normal functioning of the investment and innovation sector of the national economy and lead to the formation of negative or even destructive trends in its development. A high degree of security is achieved when all indicators have optimal values.

If an increase in the indicator value entails an increase in the Integral index, it is a stimulant, otherwise, it is a de-stimulant. For stimulating indicators, the designation "*l*(lower)" is used (for example, x_{optl}), for de-stimulating indicators, the designation "*u*(upper)" is used (for example, x_{optu}).

The justification of the characteristic values of the detected indicators that make up the set [x_1, x_2, ..., x_n] was based on a synthesis of relevant international and domestic statistical information, in particular, regarding the smallest, average, and largest values of the corresponding indicators for EU countries (or OECD in case of lack in EU statistics); and also on determining the levels of criticality, optimality, and boundary limits for different indicators. To establish the optimal and critical values of the indicators, the dynamics of corresponding indicators in Ukraine as well as the legal regulation of their values were investigated. For example, The Law of Ukraine On Scientific and Scientific-Technical Activities (Article 48) stipulates that the state provides budgetary funding for scientific and scientific-technical activities in the amount of at least

1.7% of Ukraine's GDP. The characteristic values of indicators that have limited lower values (stimulant indicators) lie within the interval [x_{critl}, x_{optl}], and of indicators that have limited upper values (de-stimulant indicators)—within the interval [x_{optu}, x_{critu}].

The criticality/optimality intervals [x_{critl}, x_{optl}] and [x_{optu}, x_{critu}] were determined according to the scheme [18]: [x_{crit}, x_{dang}), [x_{dang}, $x_{unsatisf}$), [$x_{unsatisf}$, x_{satisf}), [x_{satisf}, x_{opt}], where:

- x_{crit} is a critical level of investment and innovation security equal to 0.2, or 20% of optimal value.
- x_{dang} is a dangerous level of investment and innovation security equal to 0.4, or 40% of optimal value.
- $x_{unsatisf}$ is an unsatisfactory level of investment and innovation security equal to 0.6, or 60% of optimal value.
- x_{satisf} is a satisfactory level of investment and innovation security equal to 0.8, or 80% of optimal value.
- x_{opt} is an optimal level of investment and innovation security equal to 1.

An indicator's value $x_j < x_{crit}$ characterizes the absolutely dangerous status of the investment and innovation sphere (the security status is equal to 0).

The characteristic values of all 9 indicators for assessing the investment and innovation security of Ukraine are given in Table 3.

Table 3
Characteristic values of the investment and innovation security indicators

	X critl	X dangl	X unsatisfl	X satisfl	X optl	X optu	X satisfu	X unsafisfu	X dangu	X critu
x_1	0.9	1	1.2	1.7	3					
x_2	0.5	0.9	1	1.2	1.7					
x_3	10	12	14	16	25					
x_4	7	10	15	18	20					
x_5	1	1.25	1.5	1.75	2					
x_6	12	17	18	20	25	30	34	36	38	40
x_7	2	3	3.5	4	6	7				
x_8	12	24	29	34	39	44				
x_9						43	49	55	60	70

Source: authors' calculations.

3.3. Normalizing the Indicators Values and Obtaining a Normalised Set [$y_1, y_2, \ldots, y_n$].

Normalization of indicators, that is, transition to the unified measurement scale where the best value of the indicator corresponds to 1, and the worst value—to 0, can be carried out by several methods. Though the minimax method is quite a common technique in this case, however, only the values of x_{min} and x_{max} obtained from statistical data are taken into account, but the characteristic values described above, which play a fundamentally important role in assessing the status of investment and innovation security, are neglected.

That is why the calculation of the indicators' normalized values included in the Integral index was carried out by the provisions of the Methodological recommendations for calculating the level of economic security [18], specifically:

- for the stimulant indicators:

$$y_j = \begin{cases} 0{,}2 + 0{,}2\frac{(x_j - x_{crit})}{(x_{dang} - x_{crit})}, & x_{crit} \le x_j < x_{dang} \\ 0{,}4 + 0{,}2\frac{(x_j - x_{dang})}{(x_{unsatisf} - x_{dang})}, & x_{dang} \le x_j < x_{unsatisf} \\ 0{,}6 + 0{,}2\frac{(x_j - x_{unsatisf})}{(x_{satisf} - x_{unsatisf})}, & x_{unsatisf} \le x_j < x_{satisf} \\ 0{,}8 + 0{,}2\frac{(x_j - x_{satisf})}{(x_{opt} - x_{satisf})}, & x_{satisf} \le x_j < x_{opt} \\ 1, & x_{opt} \le x_j \end{cases} \quad (2)$$

where x_j is the value of the j^{th} indicator, y_j is the normalized value of indicator x_j.

If $x_j < x_{critl}$, then $y_j = 0$.

- for the de-stimulant indicators:

$$y_j = \begin{cases} 1, & x_j < x_{opt} \\ 0{,}8 + 0{,}2\frac{(x_{satisf} - x_j)}{(x_{satisf} - x_{opt})}, & x_{opt} \le x_j < x_{satisf} \\ 0{,}6 + 0{,}2\frac{(x_{unsatisf} - x_j)}{(x_{unsatisf} - x_{satisf})}, & x_{satisf} \le x_j < x_{unsatisf} \\ 0{,}4 + 0{,}2\frac{(x_{dang} - x_j)}{(x_{dang} - x_{unsatisf})}, & x_{unsatisf} \le x_j < x_{dang} \\ 0{,}2 + 0{,}2\frac{(x_{crit} - x_j)}{(x_{crit} - x_{dang})}, & x_{dang} \le x_j < x_{crit} \end{cases} \quad (3)$$

where x_j is the value of the j^{th} indicator, y_j is the normalized value of indicator x_j.

If $x_j > x_{critu}$, then $y_j = 0$.

Normalization of mixed-type indicators, when to a certain value it is a stimulant, and with a further increase it turns into a de-stimulant, requires a combination of calculations for stimulant indicators (for the left side, which interprets stimulation) and for de-stimulant indicators (for the right side, which interprets de-stimulation).

Within the interval of optimal values [x_{optl}, x_{optu}] the normalized value of a mixed-type indicator is equal to 1.

$$y_j = 1 \text{ when } x_{optl} \leq x_j \leq x_{optu}. \quad (4)$$

Normalized indicators' values are necessary for the calculation of the Integral index of investment and innovation security are given in Table 4.

Table 4
Normalized values of 9 indicators of investment and innovation security, 2014–2022

	2014	2015	2016	2017	2018	2019	2020	2021	2022
y_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
y_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
y_3	0.41	0.72	0.81	0.63	0.76	0.58	0.69	0.00	0.00
y_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
y_5	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
y_6	0.29	0.26	0.34	0.35	0.53	0.52	0.25	0.25	0.00
y_7	0.00	0.84	0.83	0.00	0.65	0.76	0.00	0.67	0.00
y_8	1.00	0.88	0.69	0.44	0.36	0.29	0.26	0.21	0.22
y_9	0.34	0.32	0.56	0.77	1.00	0.87	0.93	0.80	0.52

Source: authors' calculations.

3.4. Calculation of the Indicators Weighting Coefficients (a_j)

Weighting coefficients were calculated using different methods to enable further comparison of the Integral indexes depending on the calculation method used:

1) Based on correlation analysis [16] using the formula:

$$a_j = \frac{\sum_{j=1}^{n} r_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} r_{ij}}, \quad (5)$$

where a_j is the weighting coefficient, determining the degree of contribution of the j^{th} indicator to investment and innovation security, r_{ij} is the correlation coefficient between the i^{th} and j^{th} indicators characterizing the status of investment and innovation security, j = (1, 2, 3, …, n).

2) Based on the principal component method using the formula:

$$a_j = \frac{\sum_{g=1}^{l} C_{g*}|D_{jg}|}{\sum_{g=1}^{l} \sum_{j=1}^{n} C_g|D_{jg}|}, \quad (6)$$

where C_g is the contribution of the g^{th} is component to the total variance of the set of investment and innovation security indicators that contains the j^{th} indicator, D_{jg} is factor loadings of the j^{th} indicator in the g^{th} component, l is the number of components that include the j^{th} indicator. Their total variance must be at least 90%.

If multicollinearities exist, it is advisable to use the principal component method, which replaces significantly correlated indicators with the principal components, between which the correlation is much weaker.

3) Based on pairwise correlation between GDP growth rates and the values of investment and innovation indicators using the formula:

$$a_j = \frac{k_j}{\sum_{j=1}^{n} k_j}, \quad (7)$$

where k_j is the correlation coefficient between the GDP growth rate and the j^{th} indicator value.

This method was used because GDP growth increases the possibility of additional financing of scientific and innovative activities, and therefore improves investment and innovation security status.

4) Based on the expert evaluation method [18] using the formula:

$$a_j = \frac{\sum_{j=1}^{m} b_{jq}}{\sum_{q=1}^{n} \sum_{j=1}^{m} b_{jq}}, \quad (8)$$

where b_{jq} is q^{th} expert's evaluation for the j^{th} indicator, m is a number of experts.

The calculated weighting coefficients using different methods are given in Table 6.

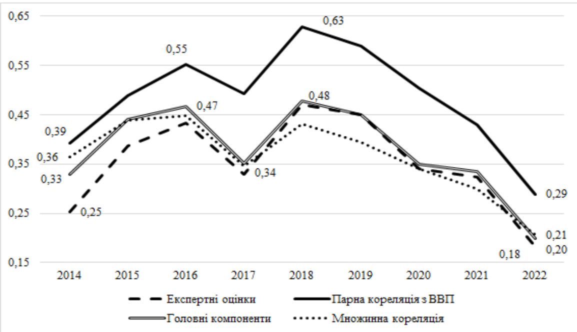
Table 6
Weighting coefficients of the investment and innovation security indicators, calculated by different methods

	Multiple correlation method	Pairwise correlation to GDP method	Principle component method	Expert evaluation method
For a set of 9 indicators				
x_1	0.1760	0.0352	0.1103	0.1163
x_2	0.1280	0.1218	0.1163	0.1163
x_3	0.0999	0.1488	0.1031	0.1085
x_4	0.0916	0.0489	0.1143	0.1163
x_5	0.1036	0.2113	0.1155	0.1163
x_6	0.0250	0.2039	0.1063	0.1163
x_7	0.0812	0.0730	0.1158	0.1085
x_8	0.1699	0.0131	0.1014	0.1163
x_9	0.1249	0.1442	0.1169	0.0853
For a set of 8 indicators				
	Multiple correlation method	**Pairwise correlation to GDP method**	**Principle component method**	**Expert evaluation method**
x_1	0.1950	0.0411	0.1151	0.1271
x_2	0.1182	0.1423	0.1295	0.1271
x_3	0.1395	0.1738	0.1232	0.1186
x_4	0.0930	0.0571	0.1299	0.1271
x_5	0.1353	0.2468	0.1343	0.1271
x_6	0.0676	0.2382	0.1304	0.1271
x_7	0.0781	0.0853	0.1245	0.1186
x_8	0.1733	0.0153	0.1132	0.1271

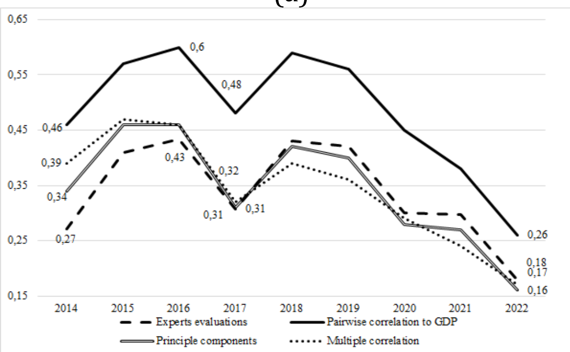
Source: authors' calculations.

3.5. Assessment of the Integral Index of Investment and Innovation Security (I) and Discussion of the Results

The results of the assessment of the Integral index of investment and innovation security (formula (1)) using indicator weights calculated by different methods (formulas (5–8)) are presented in Fig. 1.



(a)



(b)

Figure 1: Dynamics of the Integral indexes of investment and innovation security of Ukraine assessed based on weighting coefficients calculated by different methods, for a set of 9 (a) and 8 (b) indicators, 2014–2022.

As the graphs show, the dynamic trends of the Integral index of investment and innovation security of Ukraine are close regardless of the calculating methods of indicators' weighting coefficients. The estimates of the Integral index obtained from the results of the study reveal a significant deterioration in the investment and innovation security status of Ukraine in the period 2014–2022, and its rapid decline since 2018 regardless of the calculating methods of indicators' weighting coefficients: 2.6 times for a set of 9 indicators (Fig. 1a) and 2.3–2.6 times for a set of 8 indicators (Fig. 1b).

Negative dynamics of the values of the Integral index of investment and innovation security are due to the deterioration in many of its components during 2014–2022. The most difficult situation was in the sphere of R&D financing in the economy as a whole (from various sources—x_1) and from the State budget of Ukraine (x_2). Since 2014, the values of these indicators have been at levels below critical (0.9% of GDP in terms of total relevant expenditures and 0.5% of GDP in terms of financing from the state budget). At the same time, total expenditure on R&D fell from 0.6% of GDP in 2014 to 0.4% in 2020, while the average for EU countries was 1.78% of GDP, and in Sweden exceeded 3.5% of GDP. In Ukraine's neighboring EU countries, relevant expenditures ranged from 0.91% of GDP in Slovakia to 1.39% of GDP in Poland and about 2% of GDP in the Czech Republic and Slovenia [21].

The values of x_3 indicator (innovative industrial products sold in total amount of industrial products sold, percent) were also below the critical level during 2014–2022, which did not exceed 2.5% (critical level is 7%), and in 2020 amounted to 1.9%, which is 6 times less than the average for EU countries (13%), and more than 20 times behind the corresponding figure for Ireland (42.4%) [22].

For many years now, the values of the x_6 indicator (gross fixed capital formation) have been within the dangerous interval, and since 2017, the x_8 indicator (loans provided to other non-financial corporations) has also joined the dangerous interval.

The only indicator of investment and innovation security, which even exceeded the optimal value during 2014–2022 was the exports-to-imports ratio of the royalties, licensing services, computer and information services, D&D, and services in architectural, engineering, and other technical industries.

The highest value of the Integral index of investment and innovation security of Ukraine, calculated on a set of 8 detected indicators, was achieved in 2016 regardless of the calculating methods of indicators' weighting coefficients and ranged from 0.43 (using expert evaluation method) to 0.60 (using pairwise correlation method). The Integral index was also close to the maximum value in 2018 (using the multiple correlation method, slightly lower than in 2016).

The highest value of the Integral index of investment and innovation security of Ukraine, calculated on a set of 9 detected indicators, was achieved in 2018 regardless of the calculating methods of indicators' weighting coefficients and ranged from 0.43 (using the multiple correlation method) to 0.63 (using the pairwise correlation method). The Integral index was close to the maximum value in 2016 (using the multiple correlation method, even slightly higher than in 2018).

It can be seen from the graphs above, that inclusion of the Ukraine's rank in the Global Innovation Index ranking to the set of indicators when assessing the Integral index of investment and innovation security (that is, a set of 9 indicators) leads to overestimation of Integral index in certain years. Thus its exclusion from a set of indicators when assessing the Integral index is justified.

Fig. 1 shows that the maximum values of the Integral index were obtained in cases when investment and innovation indicators' weighting coefficients were calculated using the method of pairwise correlation between the indicators and GDP. In 2014–2016 the values of the Integral index calculated using this weighting method exceeded the index values obtained using three other weighting methods (principal components, multiple correlation, experts evaluations) by 8–18%, and in 2017–2022—by 28–44%.

Such assessment results are because, in contrast to the results of theoretical analysis and the experience of many countries regarding the positive relationship between factors of innovative development of national economies and GDP dynamics, in the conditions of Ukraine, correlation analysis does not reveal a significant connection between the corresponding indicators. That is why, such basic indicators are important for the security of the investment and innovation sphere, in particular, x_1 (R&D expenditures, % of GDP), x_4 (innovative industrial products (goods, services) sold in the total amount of industrial products (goods, services) sold, %), x_8 (loans provided to other non-financial corporations, % of GDP), received low weights according to this weighting method (Table 6). As a result, critically low or unsatisfactory values of initial indicators of the investment and innovation sphere in 2014–2022 did not have a negative impact on the value of the Integral index and has led to its overestimation. Consequently, when identifying weak relationships between indicators of innovative development and GDP dynamics, determining the weight of initial indicators using the method of their pairwise correlation with GDP leads to an overestimation of the Integral index of investment and innovation security, and therefore the use of this method is inappropriate.

The use of statistical weighting methods (principal components and multiple correlations) as well as the expert's evaluations do not introduce a significant error in the assessment of the values and dynamics of the Integral index of investment and innovation security of Ukraine. Testing the robustness and sensitivity of the Integral index of investment and innovation security (according to 2014–2022 data) from the point of calculating methods of the detected indicators' weighting coefficients indicates the reliability of calculations and aggregation of indicators in the Integral index of investment and innovation security using such methods.

4. Conclusions

Modeling of the Integral index of investment and innovation security of Ukraine is carried out using different approaches to calculating weighting coefficients of initial indicators that characterize the state of investment and innovation security. The use of various methods of weighting the indicators, in particular, the principle components method, the method of multiple correlation, and the method of expert evaluation, in the assessment of the Integral index of investment and innovation security provides consistent estimates of the state of investment and innovation security, which is an important component of economic security. The advantages of statistical methods over the method of expert evaluations are that they are available and unbiased. The proposed Integral indicator does not depend on the choice of the above-mentioned methods of weighing the initial indicators and is a fairly reliable tool for monitoring the state of investment and innovation security of Ukraine.

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