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**Kostiantyn Shaposhnykov**

D.Sc. in Economics, Professor, Vice-President for Scientific Work and International Relations, HEI "University of Future Transformation", Chernihiv, Ukraine;  
 e-mail: [k.s.shaposhnykov@gmail.com](mailto:k.s.shaposhnykov@gmail.com)  
 ORCID: [0000-0003-0640-9934](https://orcid.org/0000-0003-0640-9934)  
 (Corresponding author)

**Alla Shlapak**

D.Sc. in Economics, Associate Professor, Vice-Rector for Scientific and Pedagogical Work and Innovative Development, Borys Grinchenko Kyiv University, Kyiv, Ukraine;  
 ORCID: [0000-0001-8697-7039](https://orcid.org/0000-0001-8697-7039)

**Denys Krylov**

D.Sc. in Economics, Associate Professor of the Department of Finance, Banking and Insurance, Zaporizhzhia National University, Zaporizhzhia, Ukraine;  
 ORCID: [0000-0001-8522-5433](https://orcid.org/0000-0001-8522-5433)

**Inna Yakushko**

D.Sc. in Economics, Head, Main Department of the State Tax Service in Kyiv, Kyiv, Ukraine;  
 ORCID: [0009-0005-2576-9478](https://orcid.org/0009-0005-2576-9478)

**Oleksandra Tsyra**

Candidate of Psychological Sciences, Associate Professor of the Department of Public Administration and Digital Economy, State University of Intelligent Technologies and Telecommunications, Odesa, Ukraine;  
 ORCID: [0000-0003-3552-2039](https://orcid.org/0000-0003-3552-2039)

**Kateryna Nykoniuk**

Department of the International Economy, Borys Grinchenko Kyiv University, Kyiv, Ukraine;  
 ORCID: [0000-0002-2271-1538](https://orcid.org/0000-0002-2271-1538)

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# DEVELOPMENT OF INNOVATIVE INFRASTRUCTURE OF THE NATIONAL ECONOMY UNDER CONDITIONS OF DIGITALIZATION OF FINANCIAL AND ECONOMIC SYSTEM MANAGEMENT

## ABSTRACT

The study clarifies the essence of innovation infrastructure as a digitally-oriented ecosystem, develops an integrated model of its development based on the triple helix model, taking into account the digital component. Digitalization (Weighted index IID), which takes into account the different significance of eight key indicators. The empirical study was conducted based on the comparative analysis of Ukraine with six countries (Norway, Estonia, Poland, Slovakia, Romania, and Moldova). The main results of the study showed that Ukraine ranks 6th among the seven countries under study in terms of the innovation development of the infrastructure, with an index value of 26.44 (compared to 169.26 in Norway and 147.34 in Estonia). The most critical weaknesses are extremely low business spending on R&D, weak network cooperation of innovatively active small and medium-sized businesses, low intensity of public-private interaction, and insufficient use of cloud technologies by enterprises. At the same time, Ukraine's relative competitive advantage is a relatively higher level of venture capital. The Weighted index IID has been tested, which takes into account the different importance of indicators for the formation of a modern innovation ecosystem. The results obtained confirm that in the digitalization context, the efficiency of innovation infrastructure is determined not so much by the presence of individual objects as by the synergy between the digital basis, financial and resource support, and network interaction of the participants in the triple helix. The identified significant imbalances indicate the need to intensify research and development in business, develop digital infrastructure, and stimulate public-private cooperation.

**Keywords:** innovation infrastructure, digitalization, triple helix, weighted integral index, venture capital, network cooperation, financial and economic system, Ukraine

**JEL Classification:** O31, O33, G20, L86

## INTRODUCTION

Under the conditions characterized by accelerated digital transformation (DT) of all spheres of public life, the innovative infrastructure of the national economy acquires a new meaning and strategic importance. Infrastructure ceases to be only a set of individual objects (technology parks, business incubators, and technology transfer centers) but turns into a key element of the digital ecosystem that ensures the interaction of science, financial resources, business, and the state in the context of digitalization management of financial and economic systems.

For Ukraine, the issue of developing innovation infrastructure is especially acute. On the one hand, the country has significant scientific and technical potential and has identified European integration as a strategic priority. On the other hand, in terms of the development level of innovation infrastructure and digital maturity, Ukraine is significantly lagging behind the countries of the European Union. This is confirmed by the European Innovation Scoreboard 2025, according to which Ukraine belongs to the "Emerging Innovator" group with low scores in most infrastructure indicators. In these conditions,

the search for effective mechanisms for the development of innovation infrastructure in the digitalization context acquires both theoretical and important practical importance.

The relevance of the study is due to the need for scientific substantiation of approaches to the formation of a modern innovation infrastructure capable of functioning in the DT context of management of financial and economic systems, as well as the development of tools for its quantitative assessment and comparative analysis.

## LITERATURE REVIEW

The transformation of economic systems under the influence of digital technologies leads to a rethinking of the essence of innovation infrastructure, which is increasingly interpreted not as a set of individual institutions, but as an integrated digitally-oriented ecosystem (Shkarlet & Dubyna, 2017; Obydiennova et al., 2024; Amir et al., 2025).

According to the approach (Etzkowitz & Leydesdorff, 2000), the effectiveness of innovative development is determined by the interaction level between universities, business, and the state. Further research confirms that it is the intensity of these interconnections that forms the basis of modern innovation ecosystems (Cai & Lattu, 2022; Bulgakova, 2025; Danylovyh et al., 2024).

In the context of DT, this model is undergoing an evolution, complemented by a digital dimension that enhances network effects and reduces the transaction costs of innovation activities. In particular, Yu et al. (2023) argue that the digital economy is changing the behavior of enterprises towards innovation, forming new mechanisms for the creation and diffusion of knowledge, while Wei (2025) emphasizes the role of digital infrastructure in increasing the efficiency of innovation processes by reducing costs and increasing the availability of resources.

Modern writings emphasize the need for an integrated approach, including digital infrastructure, financial support, networking, and mechanisms for commercializing innovations (Zybareva et al., 2023; Hryhoruk et al., 2024; Tanasiichuk et al., 2024). At the same time, digital technologies (broadband, cloud computing) are considered the basic platform for the functioning of innovation ecosystems.

The research confirms the importance of financial instruments; in particular, business R&D spending is a key driver of innovation hubs and technology clusters (Zhang et al., 2025), while venture capital plays a crucial role in bridging the gap between research and development (Kato, 2025). At the same time, government spending forms the basic scientific infrastructure that ensures the generation of knowledge.

Special attention in the scientific literature is paid to network interaction as a key element of innovation infrastructure. Audretsch et al. (2023) prove that cooperation between SMEs is a critical factor in increasing innovation activity, while the indicator of public-private publications is considered an indicator of the effectiveness of technology transfer (De Martino et al., 2026).

Ukrainian scientific research develops these approaches, including military challenges and European integration processes. In particular, Perminova et al. (2024) consider innovation infrastructure as the basis for Ukraine's economic revival during the period of military aggression, emphasizing the need for state incentives for the development of digital innovation ecosystems, including e-governance, technology transfer platforms, and networking.

Kalat et al. (2026) emphasize its importance for the resilience of regional ecosystems. Makarov (2025) emphasizes the need to develop digitally integrated research infrastructures, examines the formation of new research infrastructures in Ukraine in modern conditions, emphasizing the transition from traditional forms to digitally integrated structures that ensure the protection of intellectual property and the commercialization of the results of scientific developments. Researchers by Hrubliak et al. (2026) and Aliksieiev & Navrotskyi (2026) also confirm that digitalization is a key factor in adapting the Ukrainian economy to modern challenges.

In recent years, researchers have focused on the transformation of innovation infrastructure under the influence of the digital economy. Yu et al. (2023) show that the digital economy is radically changing the behavior of enterprises towards innovation, transforming traditional infrastructure into a digitally-oriented ecosystem, where cloud technologies and digital platforms become key elements in accelerating innovation processes. Wei (2025) explores how digitalization policies affect the innovation activity of enterprises, highlighting the role of digital infrastructure in reducing transformation costs and enhancing innovation potential.

Ukrainian scientists are developing this understanding, taking into account the realities of war, European integration, and DT. Kalat et al. (2026) conduct a systematic analysis of regional innovation infrastructure as a factor of sustainability of

regional innovation ecosystems in Ukraine and note that innovation infrastructure is not only a set of objects (technology parks, business incubators, technology transfer centers), but a structural and functional system that should provide the entire life cycle of innovations – from idea generation to scaling, with the obligatory consideration of the digital component to overcome spatial and functional imbalances.

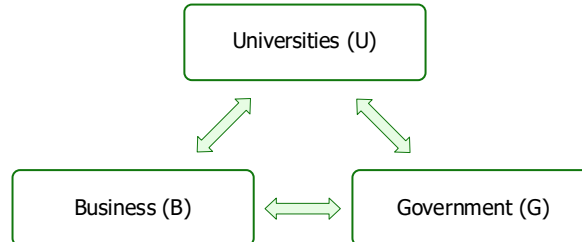
Malykhin & Voloshyn (2025) emphasize the role of financial intermediaries in the formation of the innovative infrastructure of the digital financial services market, considering it as a system that combines financial, technological, and information components in the context of digitalization.

Thus, in the digitalization context of the management of financial and economic systems, the essence of innovation infrastructure is significantly transformed. The innovation infrastructure of the national economy ceases to be a static set of physical objects and becomes a digitally-oriented ecosystem, where high-speed Internet, cloud technologies, digital platforms and network interactions provide rapid knowledge transfer, reducing barriers for startups and increasing the resilience of the national economy to external shocks.

Understanding innovation infrastructure combines systemic, ecosystem and digital approaches: it is a dynamic network that ensures the interaction of science, business, government and digital technologies to transform knowledge into competitive innovations.

The modern significance of innovation infrastructure in national innovation systems lies in its role as the main mechanism for organizing interaction between the key participants in the innovation process – universities (science), industry (business) and the state. It is this interaction that ensures the transformation of knowledge into competitive innovations and is the core of the modern theory of innovative development.

The Triple Helix Model, proposed by G. Itzkowitz and L. Leidesdorf (2020), has become one of the most influential conceptual tools for analyzing the national innovation system. In this model, innovation infrastructure is not just a set of objects (technology parks, incubators, or technology transfer centers), but a dynamic system of intersections of three “spirals” – universities, business, and the state – that are constantly changing their roles. Such interaction creates a synergistic effect that accelerates the generation, transfer, and commercialization of knowledge (Figure 1).



**Figure 1. Triple Helix Model Diagram.** (Source: compiled by the authors based on their own research)

Spirals constantly intersect and “rotate” around each other, forming hybrid institutions – science parks, venture funds, technology transfer centers. In the digital environment, these intersections are amplified by broadband, cloud technology, and digital platforms.

Thus, the theoretical significance of innovation infrastructure lies in the fact that infrastructure is not just a supporting element, but an active institutional mechanism that ensures the synergy of three components, reduces barriers between science, business, and the state, and creates conditions for effective DT of the national economy.

Cai & Lattu (2022), in their comparative analysis of triple and four-link helix models, emphasize that Triple Helix remains the most effective analytical tool for empirical research of innovation systems precisely because of the “Occam’s blade” principle: the model simplifies the complexity of real-world interactions by focusing on the three main components and their networks.

In modern Ukrainian research, the triple helix model is also considered a key conceptual framework. Danylovyh et al. (2024) state that today the model of the innovation cycle is being replaced with the “triple helix” model and, as a result, there has been a change in the emphasis, forms, and significance of educational, business, and scientific institutions in the innovation process, where the main role has begun to be played by the university infrastructure.

Bulgakova (2025), Volodin et al. (2025) develops this idea in the context of digitalization and globalization, proposing to use the triple helix model as the basis for the conceptual design of the global innovation system, highlighting three key components: international innovation cooperation, knowledge and capital flows, and institutional and legal infrastructure,

which is especially relevant for countries undergoing DT of the management of financial and economic systems.

The results of empirical studies by Ukrainian and foreign scientists confirm that the selected eight indicators adequately and comprehensively characterize the level of development of the innovation infrastructure of the national economy, especially in the context of digitalization. These indicators reflect the key components of infrastructure: digital basis, resource and financial support, network connections, technology transfer, and innovation performance:

1. High-speed internet/Broadband and Cloud computing/Use of information technologies by enterprises characterize digital infrastructure, which is the foundation of modern innovation ecosystems. Wei (2025) and Yu et al. (2023) prove that digital infrastructure (broadband and cloud technologies) significantly reduces transaction costs and accelerates the commercialization of innovations.
2. Business R&D expenditure and Public R&D expenditure reflect the resource provision of innovation infrastructure (corporate R&D centers, state scientific institutions). Research by Zhang et al. (2025) confirms that business R&D spending is one of the strongest drivers of the creation of technology parks and technology transfer centers, while government spending forms the basic scientific infrastructure.
3. Venture capital expenditures are a key financial indicator of infrastructure. Kato (2025) argues that venture capital is a catalyst for the creation of business incubators, technology parks, and the acceleration of the commercialization of innovations, especially in emerging economies.
4. Innovative SMEs collaborating with others characterizes the network component of the infrastructure (clusters, incubators). Audretsch et al. (2023) empirically confirm that SME cooperation is one of the strongest factors of innovation activity and infrastructure development.
5. Public-private co-publications reflect the effectiveness of technology transfer between science and business. De Martino et al. (2026) prove that this indicator is a reliable proxy for assessing the quality of public-private cooperation and the functioning of technology transfer centers.
6. PCT patent applications characterize the effectiveness and protection of intellectual property of innovation infrastructure. EIS 2025 and GII include PCT patents in the "Intellectual assets" dimension, considering them an important indicator of innovations entering the international market.

At the same time, the analysis of scientific literature indicates the lack of integrated approaches to the quantitative assessment of innovation infrastructure, taking into account the digital component and the importance of individual factors. Most of the existing studies either focus on individual components of the infrastructure or do not take into account their integration effect.

## AIMS AND OBJECTIVES

The purpose of the study is to theoretically substantiate and empirically assess the development of the innovation infrastructure of the national economy of Ukraine in comparison with the countries of Central and Eastern Europe and the leading countries (Norway and Estonia) in the digitalization context of the management of financial and economic systems. The objectives of the study are:

- to generalize theoretical approaches to the development of innovative infrastructure in the context of digitalization;
- to identify key indicators and drivers of innovative infrastructure development; to develop and test an integrated model and Weighted index for assessing innovative infrastructure development;
- to conduct a comparative analysis of Ukraine and selected European countries regarding digital and innovative development;
- to substantiate strategic directions for strengthening state policy in the field of digital and innovative transformation.

## METHODS

The study used general scientific methods: dialectical, systemic and structural-functional analysis, comparative method, methods of statistical analysis, calculation of integral indices, as well as data visualization methods.

Since the purpose of the study is a targeted assessment of innovation infrastructure precisely in the context of digitalization

of management of financial and economic systems, a system of eight indicators was selected for a comprehensive assessment of the level of its development, which reflect its key components:

- comprehensively cover all key components of innovation infrastructure (digital database → financing → network connections → transfer → real activity);
- have official, regular statistics (Eurostat, EIS 2025), which makes them suitable for comparing Ukraine with Poland, Estonia, Romania, Slovakia, Norway and Moldova;
- correspond to the modern concept of national innovation systems and the “triple helix” (business – universities – state), where infrastructure is not only buildings, but also mechanisms of interaction and digitalization (Table 1).

**Table 1. A set of indicators that characterize the degree of development of the innovation infrastructure of the national economy.**

Indicator group	Showman	Impact on innovation infrastructure	Justification
Digital infrastructure (the basis of a modern innovation ecosystem)	High-speed internet / Broadband	The level of access to high-speed Internet is the foundation for digital collaboration, platforms, data, and remote work	Digital infrastructure is a necessary prerequisite for the functioning of modern technology parks, incubators and network ecosystems. Without it, other elements are ineffective
Digital infrastructure	Cloud computing / Use of information technologies by enterprises	Level of use of cloud technologies and IT by enterprises	Shows the digital maturity of the business and the readiness of enterprises to use modern infrastructure (digitalization of innovations)
Financing and resource provision	Business R&D expenditure (% GDP)	Business R&D expenses	The most important indicator: business R&D centers, corporate laboratories, and investments in innovations are the basis for “renewing” the infrastructure
Financing and resource provision	Public R&D expenditure	Government spending on R&D (universities, state laboratories)	Characterizes the state scientific infrastructure, which creates a knowledge base for further transfer to business
Financing and resource provision	Venture capital	Volume of venture capital	A key element of financial infrastructure for startups and scaling innovations
Networking and cooperation	Innovative SMEs collaborating with others	Share of innovatively active small and medium-sized businesses cooperating with others	It directly reflects the efficiency of infrastructure (incubators, clusters, technology parks) – how well network connections are established
Networking and cooperation	Public-private co-publications	Joint publications of scientific institutions and business	Quality Indicator of Technology Transfer and Cooperation between Science and Business (Work of Technology Transfer Centers)
Results and protection of innovations	PCT patent applications (per 1 billion GDP)	International Patent Applications (PCT)	Reflects the level of intellectual property protection and infrastructure effectiveness (output of innovations)

In order to focus on innovation infrastructure, we deliberately moved from a general index (Summary Innovation Index) to a specialized index focused on the infrastructure component. The selected 8 indicators directly correspond to the key elements of innovation infrastructure in the current literature: digital infrastructure (1, 2); resource and financial support (3, 4, 5); network and institutional interaction (6, 7); and protection and commercialization performance (8).

Based on the fact that innovation infrastructure is not just a set of indicators, but a system that should provide funding for innovations, create network links between business, science, and the state, support the digital basis of modern technologies, and promote the commercialization of knowledge. Therefore, to assess the development level of the innovation infrastructure of the management of financial and economic systems, we take into account the different significance of these indicators.

The greatest weight was given to indicators that directly form the resource, financial, and organizational basis of innovation activity (business spending on R&D, venture capital, network interaction of enterprises). Lower weights were assigned to indicators that characterize the supporting conditions for the development of innovations (digital infrastructure, state spending on science), and the lowest weight was given to the effective indicator of patent activity, which reflects the consequences of the functioning of the innovation infrastructure, rather than its direct formation (Table 2).

**Table 2. Explanation of the weight of indicators that characterize the development level of the innovation infrastructure of the national economy.**

Indicator	Weight	Justification
R&D expenditure in the business sector	20%	The most important factor. Business spending on R&D is the basis for creating an innovative infrastructure (corporate R&D centers, internal laboratories, cooperation with universities). Without active business, the infrastructure (technology parks, incubators) remains empty. In leading countries, business finances 60-70% of R&D. However, assigning this indicator a higher weight than is appropriate from a methodological point of view, since the integral index is designed to assess the development of innovative infrastructure as a multi-component system. Despite the fact that business spending on R&D is one of the most important drivers of innovative development, it reflects only the resource aspect of the functioning of innovative infrastructure
Venture capital expenditures	18%	A very high weight, because venture capital is a key element of the financial infrastructure for startups and scaling innovations. VC Allows "Death Valley" Between Research and Market
Innovative SMEs collaborating with others	15%	High weight, since the network cooperation of SMEs is the basis of clusters, business incubators, and joint projects. Innovations today are rarely created alone. This indicator well reflects the efficiency of infrastructure (incubators, technology parks, clusters)
Public-private co-publications	12%	An important indicator of the quality of technology transfer and cooperation between science and business; shows how the infrastructure (transfer centers, science parks) works in practice
High-speed internet (Broadband)	10%	Digital infrastructure is a necessary basis for a modern innovation ecosystem (remote collaboration, platforms, data, AI), without which other elements are ineffective
Cloud computing	10%	It is very important for the DT of innovations, as it shows the level of digital maturity of enterprises and the use of modern infrastructure
R&D expenditure in the public sector	8%	Lower weight, because government spending creates a base (universities, state laboratories), but without business and VC rarely leads to commercial innovation
PCT patent applications	7%	The lowest weight among the selected ones, because patents are a result, not directly infrastructure, which more reflects intellectual property than the infrastructure itself (technology parks, incubators). The presence of significant investments in R&D does not always translate into the creation of new technologies suitable for legal protection and further commercialization. In international practice, there are significant differences between countries in the efficiency of converting R&D costs into patent results. That is why using only financing indicators does not allow assessing how effectively the innovation infrastructure functions.

The use of a weighted index allows us to take into account the different importance of indicators for infrastructure. For example, venture capital and business R&D have a much higher weight for the creation of technology parks and incubators than individual indicators of "Human resources."

To assess the development level of the innovation infrastructure of the national economy in the digitalization context of the management of financial and economic systems, a weighted integral index of innovation infrastructure development (Weighted index IID) was calculated.

The index is built taking into account the strengthening of the role of digital technologies in the formation of modern innovation ecosystems and allows you to quantify the degree of readiness of infrastructure to work in the context of DT. The calculation is carried out as a linear weighted sum of eight key indicators according to the following formula:

$$\text{Weighted index IID} = (R\&Dbiz \times 0.20) + (VC \times 0.18) + (SMEscollab \times 0.15) + (Pub-priv \times 0.12) + (Internet \times 0.10) + (Cloud \times 0.10) + (R\&Dpub \times 0.08) + (PCT \times 0.07) \quad (1)$$

where: *R&Dbiz* – business sector expenditures on research and development; *VC* – the volume of venture capital; *SMEscollab* – share of innovatively active SMEs that carry out cooperation; *Pub-priv* – the number of joint publications of the public and private sectors; *Internet* – the level of penetration of high-speed Internet (High-speed internet / Broadband); *Cloud* – the level of use of cloud technologies by enterprises; *R&Dpub* – government spending on R&D; *PCT* – the number of international patent applications.

The use of a weighted model allows not only to compare Ukraine with other countries, but also to identify how effectively the innovation infrastructure adapts to the conditions of digitalization of the management of financial and economic systems.

For a comparative analysis of the management of six countries, the following were selected, namely: Poland, Estonia, Romania, Slovakia, Norway and Moldova. The choice of these countries is due to the following key factors:

1. **Regional context:** Poland, Romania, Slovakia and Moldova are Ukraine's immediate neighbors and countries of Central and Eastern Europe; Norway and Estonia are European countries with which economic relations can potentially develop, which allows us to take into account common historical, economic and geopolitical conditions, as well as

similar challenges associated with post-socialist transformation, integration into the European space and the influence of external threats.

2. *Innovation infrastructure*: Poland, Estonia, Romania and Slovakia are member states of the European Union, which makes it possible to assess how EU membership affects the development of innovation infrastructure. Norway, although not a member of the EU, actively participates in European programs (Horizon Europe, EEA grants) and has a high level of integration with the European scientific and innovation space. Moldova, like Ukraine, is a candidate country for accession to the EU, which makes it a particularly valuable object of comparison in terms of the prospects for European integration and adaptation to the requirements of digitalization of management.
3. *Different levels of innovation development* (according to the Global Innovation Index 2025 and the European Innovation Scoreboard 2025). The selected countries represent different groups of innovation development:
  - Norway is a highly developed country with a strong innovation system, which serves as a benchmark in the field of digitalization and effective use of venture capital (according to the Global Innovation Index 2025, 20th place among countries in the world);
  - Estonia is one of the fastest-growing EU countries in terms of innovation indicators, especially in the digital sphere (according to the Global Innovation Index 2025, 16th place among countries in the world, according to the European Innovation Scoreboard 2025 – “Strong Innovator”);
  - Poland and Slovakia are countries with a similar level to Ukraine, but with noticeable progress in digitalization and business R&D (according to the Global Innovation Index 2025, 39th and 47th places among countries in the world, respectively, according to the European Innovation Scoreboard 2025 “Emerging Innovators”);
  - Romania – allows us to show internal differences within the group of countries with a weaker degree of innovative development (according to the Global Innovation Index 2025, 49th place among countries in the world, according to the European Innovation Scoreboard 2025, “Emerging Innovators”);
  - Moldova – a candidate country with similar starting conditions and challenges to Ukraine, which makes it possible to assess the differences in the trajectories of development of innovation infrastructure (according to the Global Innovation Index 2025, Moldova ranks 74th among countries in the world and Ukraine 66th).
4. *Digital and infrastructure dimension*: Estonia and Norway are leaders in DT in Europe (e-governance, high penetration of broadband and cloud technologies), which is especially important for assessing the digitalization of the management of financial and economic systems. Poland, Romania and Slovakia demonstrate different models of DT in the countries of Central and Eastern Europe, and Moldova – similar limitations and potential.

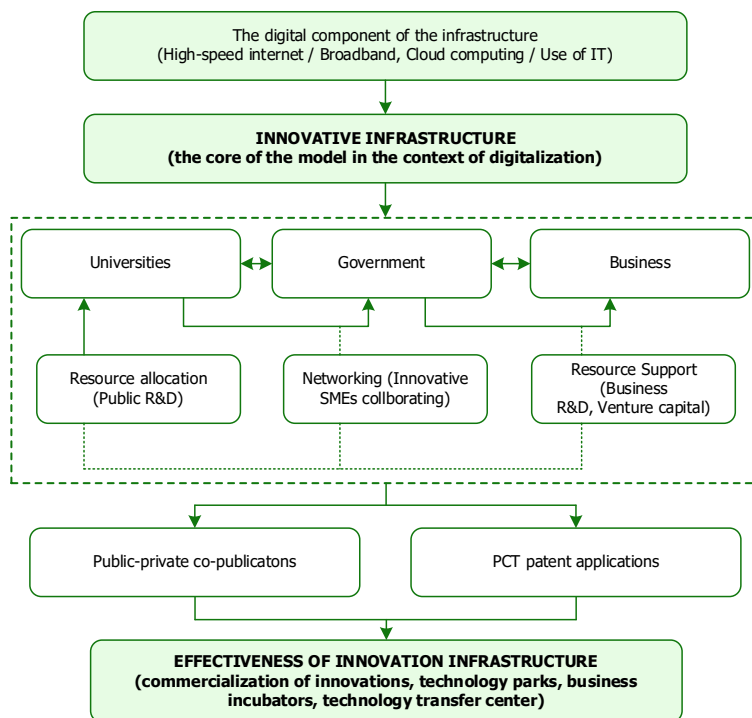
The selected group of countries allows for a comparison “on the same level” and simultaneously shows benchmarks (Norway and Estonia) and realistic goals (Poland, Slovakia). Comparing Ukraine with these countries allows, on the one hand, to identify competitive advantages and gaps in relation to countries with a similar historical and economic background, and on the other hand, to identify benchmarks and best practices for the development of innovation infrastructure in the context of digitalization. Comparison with Norway and Estonia allows us to clearly see what results a country can achieve with an effective digitalization policy and development of innovation infrastructure. Comparison with Poland, Romania and Moldova shows at what stage of reform Ukraine is in relation to countries with a similar historical and economic context.

## RESULTS

The innovation infrastructure of the national economy is an important component of the national innovation system and is a complex, dynamic system of interconnected organizations, institutions, resources and digital platforms, which ensures the creation, transfer, commercialization and diffusion of innovations at all stages of the innovation cycle in the context of digitalization of the management of financial and economic systems.

The selected indicators are not arbitrary, but are based on the internationally recognized EIS and GII methodology, as well as confirmed by empirical studies of recent years and comprehensively cover both input resources (R&D, VC, digital infrastructure) and network connections and output results of innovation infrastructure, which is especially important in the digitalization context of management of financial and economic systems.

To visualize the relationship between the classical triple helix model and empirical indicators, an integrated model has been developed (Figure 2).



**Figure 2. Integrated model for the development of innovation infrastructure based on a triple helix model in the digitalization context.**  
 (Source: compiled by the authors on the basis of their own research)

In the proposed model, the three main participants in the triple helix (universities (science), business (industry), and the state) interact through four key areas of innovation infrastructure development:

1. The digital component of the infrastructure (High-speed internet/Broadband and Cloud computing/Use of information technologies by enterprises) acts as the digital core of the model, which provides a technological platform for rapid interaction between all components, lowers the barriers of space and time, and is a necessary condition for the digitalization of the management of financial and economic systems.
2. Resource and financial support (Business R&D expenditure, Public R&D expenditure, Venture capital) forms the material and financial basis of the infrastructure. Business R&D and venture capital are mainly associated with the "Business" spiral, government spending on R&D is mainly associated with the "State" spiral, and their combination creates conditions for the emergence of new infrastructure facilities (technology parks, incubators, technology transfer centers).
3. Network and institutional interaction (Innovative SMEs collaborating, Public-private co-publications) implements the very essence of the triple helix – constant interaction and "crossing of roles" between universities, business, and the state. This area directly affects the creation of clusters, the effective operation of business incubators and technology transfer centers.
4. Efficiency (PCT patent applications and Innovation-active enterprises) is the initial result of the functioning of the entire system, which reflects how effectively the innovation infrastructure ensures the commercialization of knowledge and the introduction of innovations in the national economy.

The proposed integrated model shows that in the digitalization context of management of financial and economic systems, the digital component is not a separate element, but permeates all the interactions of the triple helix, enhancing the synergistic effect between the constituent elements. The weakness of any direction (for example, a low level of network cooperation or cloud technologies) leads to an imbalance of the entire innovation infrastructure.

This approach allows not only to diagnose the current state of innovation infrastructure, but also to determine the priority areas of the state policy of DT.

For the empirical assessment of the development level of the innovation infrastructure of the national economy in the digitalization context of the management of financial and economic systems, eight key indicators have been analyzed. The data are presented as a percentage of the EU average (100%). The comparison was made between Ukraine and six countries representing different levels of innovative development and DT (Table 3).

**Table 3. Actual values of indicators of innovation infrastructure development in the countries of comparison (% of the EU average).**  
(Source: compiled by the authors based on calculations carried out on the basis of GII 2025, EIS 2025)

Country	High-speed internet / Broadband	Business R&D expenditure	Public R&D expenditure	Venture capital	Innovative SMEs collaborating	Public-private co-publications	PCT patent applications	Cloud computing / Use of IT by enterprises
Norway	124.2	69.7	113.3	121.0	238.9	459.3	78.7	155.9
Estonia	96.8	70.3	106.7	270.0	165.7	204.5	51.9	134.3
Poland	103.9	66.2	71.7	20.1	48.1	62.6	41.4	126.8
Slovakia	83.6	37.2	55.0	18.6	71.2	78.7	45.0	71.8
Romania	127.5	19.3	13.3	12.6	0.00	36.5	25.6	30.3
Ukraine	85.0	10.4	5.0	43.5	7.6	13.8	33.3	25.0
Moldova	60.0	0.1	9.8	0.0	36.7	4.8	20.3	15.0

Comparative analysis shows that the differences between countries lie not only in the absolute level of individual indicators, but primarily in the balanced development of the components of the innovation infrastructure. The study shows the existence of two fundamentally different development models.

The first model is typical for Norway and Estonia, where high indicators of digital infrastructure are combined with significant amounts of research and development funding, developed venture capital, and intensive interaction between business and the scientific sector. It is especially indicative that the high level of business spending on R&D is accompanied by high values of indicators of cooperation of innovative enterprises and joint publications. This indicates the presence of a holistic innovation ecosystem in which financial, digital and institutional elements mutually reinforce each other.

The second model is typical for countries with fragmented development of innovation infrastructure, which include Ukraine, Romania and Moldova. These countries are characterized by the presence of individual relatively strong components in the absence of systemic interaction between them. In particular, Romania has one of the best indicators of access to broadband Internet (127.5% of the EU average), but demonstrates low results in terms of R&D financing, venture capital, and cooperation of innovative enterprises. That is, the development of digital infrastructure in itself does not ensure the formation of an effective innovation system.

Ukraine is characterized by an even more pronounced structural imbalance. A relatively acceptable level of digital accessibility (85.0% of the EU average) and venture capital (43.5%) is not accompanied by a sufficient level of R&D financing and network interaction between innovation entities. Particularly critical is the lag in the indicators of cooperation of innovative small and medium-sized enterprises (7.6%) and joint scientific and business publications (13.8%), which are indicators of the effectiveness of knowledge transfer mechanisms. Thus, the main problem of Ukraine is not so much the insufficient level of digitalization, but the weakness of institutional mechanisms of interaction between science, business and the state.

An important result of the study is the finding that a high level of patent activity does not always directly depend on the level of digital infrastructure. For example, Ukraine demonstrates a higher level of international patent activity (33.3%) than Romania (25.6%), despite significantly worse digital infrastructure indicators. This indicates the presence of scientific and technological potential, which is not provided with proper mechanisms for commercialization and scaling of innovations.

Ukraine ranks second to last among the comparison countries by most indicators, ahead only of Moldova. The largest gaps are observed in business R&D, network cooperation, public-private interaction, and the use of cloud technologies. At the same time, a relative strength, venture capital, creates a certain potential for accelerated development of innovation infrastructure, provided that the digital component and network integration are strengthened. The results obtained confirm the need for a targeted policy of digitalization of management of financial and economic systems to overcome existing imbalances.

The results obtained confirm that the key factor in the development of innovation infrastructure is not individual elements, but their interaction. It is the combination of R&D financing, digital infrastructure, venture capital, and effective network connections that ensures the formation of a sustainable innovation ecosystem. For Ukraine, the priority area should be not only the increase in the resource provision of innovations, but also the development of institutional mechanisms for cooperation between scientific institutions, business and the state, which is a necessary condition for the digital transformation of the management of financial and economic systems.

For a comprehensive quantitative assessment of the development level of the innovation infrastructure of the national economy in the digitalization context of management of financial and economic systems, a weighted integral index of innovation infrastructure development (Weighted index IID) has been calculated.

The index is built on the basis of eight key indicators, taking into account their theoretical and practical significance for the formation of a modern innovation ecosystem. The weighting factors reflect the priority of factors in the context of DT: business spending on R&D, venture capital, and network cooperation of enterprises received the greatest weight (Table 4).

**Table 4. Calculation of the weighted integral index of innovation infrastructure development (Weighted index IID) in the countries of comparison, 2025.** (Source: compiled by the authors based on calculations)

Country	R&D biz (20%)	CV (18%)	SMEs collab (15%)	Pub-priv (12%)	Internet (10%)	Cloud (10%)	R&D pub (8%)	PCT (7%)	Weighted index IID	Rank
Norway	13.94	21.78	35.84	55.12	12.42	15.59	9.06	5.51	169.26	1
Estonia	14.06	48.60	24.86	24.54	9.68	13.43	8.54	3.63	147.34	2
Poland	13.24	3.62	7.22	7.51	10.39	12.68	5.74	2.90	63.30	3
Slovakia	7.44	3.35	10.68	9.44	8.36	7.18	4.40	3.15	54.00	4
Romania	3.86	2.27	0.00	4.38	12.75	3.03	1.06	1.79	29.14	5
Ukraine	2.08	7.83	1.14	1.66	8.50	2.50	0.40	2.33	26.44	6
Moldova	0.02	0.00	5.51	0.58	6.00	1.50	0.78	1.42	15.81	7

The results of calculating the weighted integral index indicate a significant differentiation of the level of development of the innovation infrastructure of the studied countries in the conditions of digitalization of management of financial and economic systems. The integral index allows not only to rank countries by the level of development of innovative infrastructure, but also to reveal the structural features of the formation of innovative ecosystems in the conditions of digitization of management of financial and economic systems.

The obtained results show that there is a significant gap between the leading countries and the countries that are at the stage of transformation of the innovation system. The index values of Norway (169.26) and Estonia (147.34) are more than 5 times higher than the index of Ukraine (26.44). This shows that the efficiency of the innovation infrastructure is determined not by individual elements, but by the synergy between the digital infrastructure, financing of innovations, and mechanisms of interaction of the participants of the innovation process.

It is significant that Estonia, having a smaller economic potential compared to many European countries, forms one of the highest integrated indicators thanks to the development of venture capital, digital technologies and cooperation between business and scientific institutions. That is, the determining factor in the development of innovative infrastructure is not the scale of the economy, but the effectiveness of institutional mechanisms for supporting innovations.

A different development model is characteristic of Poland and Slovakia. Despite a fairly high level of digitalization, their integral indicators are almost three times lower than the indicators of the leaders. That is, digital infrastructure is a necessary but not sufficient condition for the development of an innovative ecosystem. The lack of sufficient funding for R&D and the weaker development of the venture market significantly reduce the effectiveness of using digital opportunities to create and commercialize innovations.

The lowest indicators are demonstrated by Romania (29.14), Ukraine (26.44), and Moldova (15.81).

The results of Ukraine are of special scientific interest. The most critical weaknesses are:

- extremely low business R&D costs (2.08 points);
- weak network cooperation of SMEs (1.14 points);
- low level of public-private publications (1.66 points);
- insufficient use of cloud technologies by enterprises (2.50 points).

The obtained value of the integral index demonstrates that the main problem of the national innovation infrastructure is not so much technological lag, but insufficient integration of its components. Despite the presence of certain competitive advantages, in particular, a relatively higher level of venture capital compared to Romania and Moldova, the system does not ensure the effective transformation of financial resources into the results of innovation activity. This is evidenced by the extremely low indicators of cooperation of innovative SMEs and interaction between business and scientific institutions.

In fact, the results of the study confirm the hypothesis that the key limitation of the development of Ukraine's innovation infrastructure is the institutional gap between knowledge generation, innovation financing, and their commercialization. That is why, even with the presence of certain resource advantages, the innovation system does not form a sufficient multiplier effect for the digital transformation of the economy.

Thus, the decisive factor in the development of innovation infrastructure is not the maximization of individual indicators, but ensuring the balanced development of digital, financial, scientific and network components. It is the balance of these elements that explains the high results of Norway and Estonia and at the same time serves as the main direction for improving Ukraine's innovation policy.

Based on the results of empirical research and the calculation of the Weighted Integrated Index of Innovation Infrastructure Development (Weighted index IID), practical recommendations aimed at overcoming the identified critical gaps are:

1. Significantly increase the stimulation of business spending on R&D (the most critical factor), strengthen tax breaks, and grant co-financing for enterprises that invest in their own R&D centers or joint projects with universities.
2. Launch the National Program for the Development of the Venture Ecosystem in order to bring the Venture Capital indicator to a level not lower than 80–100% of the EU average by 2030.
3. Create a system for stimulating network cooperation, introduce a mandatory condition for a consortium form of participation (university + business + SME) to receive state funding for innovation projects and grants.
4. Actively develop cooperation with universities and scientific institutions through the creation of joint laboratories, research consortia, and participation in the activities of business incubators and technology parks.
5. Create and develop university business incubators and science parks with the real involvement of the private sector in management and investment.
6. Introduce annual monitoring of the development of innovation infrastructure according to the proposed Weighted index IID at the national and regional levels.

The implementation of the proposed recommendations will allow Ukraine to significantly increase the value of the Weighted index IID, leave the group of outsider countries and approach the level of countries such as Poland and Slovakia in the medium term, and in the long term – to the level of Estonia.

## DISCUSSION

The results of the study are consistent with the provisions of the theory of the digital economy, according to which digital technologies act as a key driver of transformation of innovation systems (Yu et al., 2023; Wei, 2025; Amir et al., 2025).

The results of the study demonstrate that the leading countries (Norway, Estonia) achieve high values of innovation infrastructure due to a comprehensive combination of digital base, financial support, and networking. This confirms the findings of (Hrubliak et al. 2026) on the approaches to the integration of the digital economy and sustainable development.

The results obtained indicate its further transformation. If the classical model focuses on the interaction of universities, business and the state (Etzkowitz & Leydesdorff, 2000), then in the digitalization context, the level of digital integration of these interactions becomes the determining factor. This is confirmed by research by Bulgakova (2025), which emphasizes the role of digital technologies in improving the efficiency of public administration and innovative development.

The identified disparities in Ukraine are generally consistent with the results of previous studies (Perminova et al., 2024; Kalat et al., 2026; Makarov, 2025); however, this study allows for a clearer identification of their quantitative parameters. In particular, the critically low level of business spending on R&D confirms the conclusions of Zhang et al. (2025) on the decisive role of the private sector in the formation of innovation infrastructure.

Low rates of cooperation between SMEs and public-private publications indicate an insufficient level of integration of the innovation system, which contradicts the conclusions of Audretsch et al. (2023) on the key role of cooperation in ensuring innovative development. Thus, Ukraine's innovation infrastructure is fragmented, which reduces its efficiency.

At the same time, the relatively higher level of venture capital in Ukraine confirms the potential for the development of the innovation ecosystem. However, as noted by Abramova et al. (2021) and Kato (2025), the effectiveness of venture financing depends on the availability of developed infrastructure and network connections, without which investments cannot be transformed into sustainable innovative development.

The results obtained also have important practical implications. They confirm the need to form a comprehensive state policy aimed at developing digital infrastructure, stimulating business R&D, and strengthening interaction between key actors of the innovation system. This is consistent with approaches regarding sustainable development strategies in the context of digitalization (Tanasiichuk et al., 2024).

At the same time, the results of the study indicate the presence of certain limitations associated with the use of aggregated indicators and expert determination of weighting factors. This opens up prospects for further research aimed at improving the methodological tools for assessing innovation infrastructure, in particular with the use of more complex econometric models.

Thus, the analysis confirms that in the context of digitalization, the effectiveness of innovation infrastructure is determined by the level of integration of its components, digital maturity and intensity of interaction between participants in the innovation process.

Despite the fact that the European Innovation Scoreboard uses a much wider list of indicators (32-35) to calculate the Summary Innovation Index, this study deliberately uses a narrower but targeted set of 8 key indicators. This choice is due to the specifics of the study's purpose – to assess the state of the innovation infrastructure, and not the overall level of innovation development of the country. The selected indicators (High-speed internet, Cloud computing, Business R&D expenditure, Public R&D expenditure, Venture capital, Innovative SMEs collaborating, Public-private co-publications and PCT patent applications) most accurately and directly characterize the key elements of modern innovation infrastructure: digital foundation, resource and financial support, network and institutional interaction, as well as performance. Using the full set of EIS indicators would lead to a significant "dilution" of the infrastructure component among other blocks (human capital, employment in high-tech sectors, sales of innovative products, etc.). The proposed approach allows for a clearer and more accurate diagnosis of innovation infrastructure in the context of digitalization.

The use of expert weighting factors further increases the analytical value of the index, as it takes into account the different significance of each factor for the development of infrastructure. The results obtained differ from the general conclusions of the European Innovation Scoreboard, which is a natural consequence of the more specialized focus of this study. This does not contradict the official methodology, but complements it, providing a deeper, infrastructure-oriented analysis, which is especially important for the formation of targeted state policy.

## CONCLUSIONS

The study of the development of the innovation infrastructure of the national economy in the digitalization context of management of financial and economic systems made it possible to obtain a number of important theoretical and practical results:

1. The essence of the "innovation infrastructure" concept in modern conditions has been clarified. It is shown that in the digitalization era, innovation infrastructure is transformed from a set of individual objects (technology parks, incubators, technology transfer centers) into a digitally oriented ecosystem that ensures the interaction of universities, business, and the state within the framework of the triple helix model. The digital component becomes not an auxiliary, but a system-forming element of the infrastructure.
2. An integrated model for the development of innovation infrastructure based on a triple helix in the digitalization concept has been developed, which combines four key areas: the digital component, resource and financial support, network and institutional interaction, as well as the effectiveness of innovation activities. The model allows you to visualize and explain the relationships between participants and infrastructure indicators.
3. A weighted integral index for the development of innovation infrastructure in the digitalization context (Weighted index IID), which takes into account the different significance of indicators for the formation of a modern innovation ecosystem, has been proposed and tested. The index is based on eight indicators and allows for comparative analysis between countries.
4. According to the results of the empirical study, it was found that Ukraine ranks penultimate (6th) among the seven countries studied (Norway, Estonia, Poland, Slovakia, Romania, Ukraine, Moldova) in terms of the level of development of innovation infrastructure. The value of the Weighted index IID for Ukraine is only 26.44, which is 6.4 times lower than Norway and 5.6 times lower than Estonia.

5. The main critical factors that hinder the development of innovation infrastructure in Ukraine in the digitalization context have been identified:
- extremely low level of business spending on R&D;
  - weak network cooperation of innovatively active small and medium-sized businesses;
  - low intensity of public-private interaction;
  - insufficient use of cloud technologies by enterprises.

At the same time, a relatively higher level of venture capital is a relative competitive advantage.

The effectiveness of the study is confirmed by the fact that the results obtained can be used in the development of state policy in the field of innovative development and DT, the formation of strategies for the development of innovation ecosystems at the national and regional levels, as an analytical basis for monitoring the effectiveness of the implementation of the strategy for the development of innovation activity in Ukraine.

Thus, the study proves that without a comprehensive strengthening of business R&D, network cooperation and digital infrastructure, the further development of Ukraine's innovation infrastructure will be significantly limited. Overcoming the identified imbalances requires a systematic policy of digitalization of the management of financial and economic systems, aimed at intensifying the interaction between science, business and the state.

The results obtained open up prospects for further scientific developments. In particular, it is advisable to develop a regional version of the weighted index to assess interregional disparities in Ukraine; to investigate the impact of individual state policy instruments (tax incentives, public-private partnerships, digital platforms) on the value of the Weighted index IID.

## ADDITIONAL INFORMATION

### AUTHOR CONTRIBUTIONS

*All authors have contributed equally.*

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### CONFLICT OF INTEREST

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Шапошников К., Шлапак А., Крилов Д., Якушко І., Цира О., Никонюк К.

## РОЗВИТОК ІННОВАЦІЙНОЇ ІНФРАСТРУКТУРИ НАЦІОНАЛЬНОЇ ЕКОНОМІКИ В УМОВАХ ЦИФРОВІЗАЦІЇ УПРАВЛІННЯ ФІНАНСОВО-ЕКОНОМІЧНИМИ СИСТЕМАМИ

Метою дослідження є теоретичне обґрунтування та емпірична оцінка рівня розвитку інноваційної інфраструктури національної економіки в умовах цифровізації управління соціально-економічними системами. У дослідженні уточнено суть інноваційної інфраструктури як цифрово орієнтованої екосистеми, розроблено інтегровану модель її розвитку на основі моделі потрійної спіралі з урахуванням цифрової складової. Запропоновано авторський зважений інтегральний індекс розвитку інноваційної інфраструктури в умовах цифровізації (Weighted index IID), який урахує різну значущість восьми ключових показників. Емпіричне дослідження проведене на основі порівняльного аналізу України з шістьма країнами (Норвегією, Естонією, Польщею, Словаччиною, Румунією та Молдовою). Основні результати дослідження показали, що Україна посідає 6-те місце між семи досліджуваних країн за рівнем розвитку інноваційної інфраструктури зі значенням індексу 26,44 (при 169,26 у Норвегії та 147,34 в Естонії). Найбільш критичними слабкими місцями є надзвичайно низькі бізнесові витрати на НДДКР, слабка мережева співпраця інноваційно активних малого й середнього бізнесу, низька інтенсивність публічно-приватної взаємодії та недостатній рівень використання хмарних технологій підприємствами. Водночас відносною конкурентною перевагою України є порівняно вищий рівень венчурного капіталу. Отримані результати підтверджують, що в умовах цифровізації ефективність інноваційної інфраструктури визначається не стільки наявністю окремих об'єктів, скільки синергією між цифровою основою, фінансово-ресурсним забезпеченням і мережевою взаємодією учасників потрійної спіралі. Виявлені суттєві диспропорції свідчать про необхідність комплексної державної політики, спрямованої на активізацію бізнес-R&D, розвиток цифрової інфраструктури та стимулювання публічно-приватної співпраці.

**Ключові слова:** інноваційна інфраструктура, цифровізація, потрійна спіраль, зважений інтегральний індекс, венчурний капітал, мережева співпраця, фінансово-економічна система, Україна

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