

УДК 330.341.1:332.1(477)

<https://doi.org/10.32342/3041-2137-2026-2-65-2>

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INNOVATION ECOSYSTEMS AND THE MODERNIZATION OF HIGH-TECH PRODUCTION AT THE REGIONAL LEVEL IN UKRAINE

Amidst the new challenges facing Ukraine's economy, the problem of finding and implementing effective tools for structural modernization and the transition from a resource-based to a high-tech economic model has become a pressing issue. A key stage of this modernization is the formation of regional innovation ecosystems. According to the theoretical approach, innovation ecosystems are not merely a collection of separate structural elements, but a dynamic system of interconnected economic and social actors that, through cooperation networks, foster the creation of innovations, attract investment and enhance economic competitiveness. The purpose of this study is to assess the impact of the infrastructural elements of the innovation ecosystem on the volume of high-tech production in the regions of Ukraine, which will allow for the identification of the most effective tools for stimulating innovation activity. An econometric analysis was conducted using regional statistical data and employing a Tobit model to account for the specific nature of the data. The results of the analysis confirmed the research hypothesis that the considered infrastructure objects have a positive and statistically significant impact. The analysis also revealed that science parks demonstrated the largest positive effect, confirming their key role in generating innovations, while innovation technology platforms and technology parks also have a substantial, albeit somewhat smaller, impact on the regional development of the high-tech sector. Thus, the study empirically proves that the greatest returns are generated by those infrastructure objects that create and support links between the key actors of the ecosystem, namely science institutions and business. This confirms that synergistic effects



within the ecosystem arise precisely at the intersection of fundamental knowledge and its practical commercialization. The obtained conclusions can serve as a basis for formulating priority measures of state policy for stimulating innovation development in the context of ensuring the post-war recovery of Ukraine's economy.

Keywords: *innovation ecosystem, institutional change, high-tech production, regional development, innovation-driven modernization, innovation policy, post-war recovery*

JEL classification: *O38, R11, R58*

В умовах новітніх викликів для економіки України актуалізується проблема пошуку і використання дієвих інструментів структурної модернізації та переходу від сировинної до високотехнологічної моделі економіки. Ключовим етапом зазначеної модернізації є формування регіональних інноваційних екосистем. Згідно з теоретичним підходом інноваційні екосистеми – це не просто сукупність окремих структурних елементів, а динамічна система взаємопов'язаних економічних та соціальних акторів, що через мережі співпраці сприяють створенню інновацій, залученню інвестицій та підвищенню конкурентоспроможності економіки. Метою даного дослідження є оцінка впливу інфраструктурних елементів інноваційної екосистеми на обсяг виробництва високотехнологічної продукції в регіонах України, що дозволить ідентифікувати найбільш ефективні інструменти стимулювання інноваційної діяльності. На основі регіональних статистичних даних, з використанням економетричної Тобіт-моделі для врахування специфіки даних, було проведено економетричне моделювання. Результати проведеного аналізу підтвердили сформовану дослідницьку гіпотезу про те, що розглянуті інфраструктурні об'єкти мають позитивний та статистично значущий вплив. Аналіз також засвідчив, що найбільший позитивний ефект продемонстрували наукові парки, що підтверджує їхню ключову роль у генерації інновацій, тоді як інноваційні технологічні платформи та технологічні парки також чинять суттєвий, хоча і дещо менший, вплив на регіональний розвиток високотехнологічного сектору. Проведене дослідження емпірично доводить, що найбільшу віддачу генерують ті об'єкти інфраструктури, які створюють і підтримують зв'язок між ключовими акторами екосистеми, а саме наукою та бізнесом. Це підтверджує, що синергетичні ефекти в екосистемі виникають саме на перетині фундаментальних знань та їх практичної комерціалізації. Отримані висновки можуть слугувати основою для формування пріоритетних заходів державної політики щодо стимулювання інноваційного розвитку в контексті забезпечення післявоєнного відновлення економіки України.

Ключові слова: *інноваційна екосистема, інституційні зміни, високотехнологічне виробництво, регіональний розвиток, інноваційна модернізація, інноваційна політика, повосенне відновлення*

JEL classification: *O38, R11, R58*

Problem statement. It is widely recognized that in the context of global bifurcations, the problem of the structural transformation of the economic system becomes particularly pressing. A resource-based export model has inherent vulnerabilities that, in the long run, limit the potential for economic growth and increase dependence on external market conditions. This situation necessitates the search for and implementation of a new economic model capable of ensuring the economy's resilience and competitiveness.

A key component of this transformation is the formation of a knowledge-based economy, which involves the prioritized

development of high-tech and science-intensive sectors. The development of Ukraine's innovation ecosystem and its integration into the European and global innovation space are necessary preconditions for the development of human capital. Under these circumstances, the issue of identifying and substantiating effective public policy instruments aimed at stimulating innovation activity at the regional level acquires special theoretical and practical significance.

Despite the recognition of innovation-driven development as a priority, there is currently a limited number of empirical studies that assess the effectiveness of the innovation ecosystem. Furthermore, the

scientific and practical problem of identifying the most influential factors that stimulate high-tech production at the regional level remains unresolved.

Literature review. Recent studies confirm that innovation ecosystems impact high-tech production. Specifically, researchers have demonstrated that in the mechanical engineering sector, the innovation ecosystem enhances the innovative performance of enterprises, as a lack of cooperation between scientific institutions and production or insufficient funding for research and development (R&D) can lead to a slowdown in the industry's innovative development [13]. A study of innovation ecosystems in China revealed that although a basic environment for innovation has been generally formed, the effectiveness of these ecosystems varies significantly between regions, as innovative interaction is strengthening in some provinces while others lag behind [22]. Digital innovation ecosystems also demonstrate a significant impact on economic development. According to a panel study of 30 regions in China (2010-2022), a high degree of niche alignment within the digital innovation ecosystem substantially contributes to high-quality economic development. Regions with more developed ecosystems are characterized by an increased level of innovation activity, leading to higher productivity and long-term growth. Moreover, it is important to note that this positive effect is sustainable over time, as the improvement in economic indicators manifests itself gradually with the development of the ecosystem itself [8]. Ukrainian researchers emphasize the necessity of close interaction among science, business and other stakeholders for long-term innovative progress and sustainable socio-economic growth [12]. They also substantiate the use of the ecosystem approach as an effective tool for stimulating the economic development of territories in order to overcome regional disparities [10].

The purpose of the article. The purpose of this article is to investigate the impact of the innovation ecosystem on the modernization of high-tech production at the

regional level in Ukraine, in order to identify the most effective instruments for regional innovation policy.

Results. The concept of the "ecosystem" was borrowed from biology, where it was first introduced into scientific discourse by the British botanist A. Tansley in 1935 [17]. To achieve conceptual clarity in this article, the analysis is based on the definition of an innovation ecosystem proposed by Granstrand and Holgersson, according to which an innovation ecosystem is an evolutionary set of actors, activities and artefacts, as well as the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors [3].

It is important to clarify these components: actors are understood as the organizations and individuals engaged in innovation activity; activities are the processes occurring within the ecosystem (e.g., R&D, financing, product development, commercialization, education and policymaking); artefacts are the tangible and intangible outcomes of these activities (technologies, products, services, patents, software and scientific publications); institutions are the formal "game rules" (laws, regulations, intellectual property rights) and informal norms (cultural values, business practices) that structure interactions among actors; relations encompass not only cooperation and complementarity but also competition and substitution [3].

Under these conditions an innovation ecosystem is composed of diverse actors, each fulfilling unique functions and contributing to the system's overall performance. Moreover, their roles within the ecosystem evolve over time. For example, in addition to their traditional functions of education and research, universities increasingly contribute to economic and social development through the formation of their own innovation subsystems [18]. Meanwhile, start-ups act as "change engines" by introducing novel ideas, technologies and business models. Established companies, in turn, provide start-ups with access to resources (financial,

manufacturing), markets and distribution channels and also serve as potential acquirers. This interaction forms the core of the open innovation model, wherein firms leverage external knowledge and technologies to accelerate their internal innovation processes [2]. The role of the state in innovation ecosystems is multifaceted, evolving from a provider of critical funding to a creator of conducive “game rules” that encourage innovation [9].

Of significant importance to the innovation ecosystem are also infrastructural entities that create physical and virtual spaces for interaction, commercialization, and innovation. These include, among others, science, technology and industrial parks, as well as innovation technology platforms, which facilitate the interaction, resource and knowledge exchange that is vital for the ecosystem’s functioning and dynamic development.

For instance, science and technology parks are key infrastructural elements of the knowledge economy. These are specially organized territories that bring together innovative companies, universities, research institutes to foster innovation and the commercialization of technology. Their primary objective is to promote a culture of innovation and enhance business competitiveness [11]. Although these types of parks are often used synonymously in academic discourse, some researchers highlight their fundamental differences. Science parks typically have closer ties to universities and research institutions, whereas technology parks may be more oriented towards industrial centres and integration with corporate R&D departments.

In contrast to physical science and technology parks, innovation technology platforms are predominantly digital environments that serve as the ecosystem’s virtual infrastructure. They eliminate geographical and organizational barriers, facilitating interaction among globally distributed participants [21]. Thus, by creating the necessary conditions for interaction, resource and knowledge exchange, well-functioning innovation ecosystems, as

substantial evidence suggests, are powerful drivers of economic growth, total factor productivity and an improved quality of life. Digital technologies, an integral component of modern innovation ecosystems, serve as the “new engine” of global economic growth [14]. Consequently, innovation ecosystems can enhance national and regional competitiveness by stimulating high-tech exports and creating favourable conditions for start-ups to compete successfully in strategic sectors.

It is important to note that innovation ecosystems do not exist solely at the national level. Recent research increasingly recognizes regional innovation ecosystems as a distinct and critically important level of analysis [1]. Furthermore, each regional innovation ecosystem (at the district, oblast or even community level) is unique and its development is largely shaped by the local cultural, economic and institutional environment, which, in turn, may be rendered ineffective by various institutional dysfunctions [4]. Simultaneously, the innovation ecosystem acts as a catalyst for a co-evolutionary process, leading to the structural modernization of not only individual regions but of the entire country [7].

The development of the innovation ecosystem is directly linked to the need for structural changes in the economy. For a country like Ukraine, with its predominantly resource-based economy, forming an effective innovation ecosystem is a precondition for the accelerated development of high-tech sectors [6], as these sectors create the conditions for a breakthrough into global high-tech markets, transforming the nation into a highly developed state with advanced technologies. Consequently, the innovation ecosystem is not merely a contributing factor but a central component of achieving innovation-driven economic modernization. It is this ecosystem that shapes the environment for collaboration and competition among actors, a necessary condition for the creation, dissemination and commercialization of innovations that underpin a modern, competitive economy [20]. It is also crucial to understand that

the functioning of an innovation ecosystem is inextricably linked to the availability of skilled human capital. In this context, attention should be drawn to the labour market challenges recorded in Ukraine during 2022–2023, notably the surge in unemployment to 18–21% and significant migration processes [15]. Other challenges facing the Ukrainian innovation ecosystem include limited access to venture capital, weak technology transfer mechanisms and an excessive dependence on foreign investment [19]. This underscores the need to find internal growth factors, one of which is precisely the development of innovation infrastructure.

This research, therefore, proposes a hypothesis regarding the positive impact of innovation ecosystem development,

specifically through an increase in the number of science parks, technology parks and innovation platforms, on the volume of high-tech production in the regions of Ukraine. To quantitatively assess the impact of these innovation ecosystem components on the modernization of high-tech production and to confirm or refute the proposed hypothesis, an econometric analysis was conducted based on statistical data from 25 administrative-territorial units of Ukraine for the year 2023 (table 1). The sample does not include the temporarily occupied territories of the Autonomous Republic of Crimea and the city of Sevastopol due to the absence of official statistical information for the period under study.

Table 1

Descriptive statistics of the variables*

Region	Output_high, thsd. UAH	Science parks, units	Technology parks, units	Innovation technology platforms, units
Vinnitsia Oblast	1890323,5	0	0	0
Volyn Oblast	995546,1	0	0	0
Dnipropetrovsk Oblast	3941501,6	1	0	3
Donetsk Oblast	631,3	0	0	0
Zhytomyr Oblast	916887,4	0	0	1
Zakarpattia Oblast	1771944,7	1	0	0
Zaporizhzhia Oblast	0	1	0	1
Ivano-Frankivsk Oblast	228811,7	2	1	0
Kyiv Oblast	228811,7	0	0	0
Kirovohrad Oblast	1342001	1	1	0
Luhansk Oblast	0	0	0	0
Lviv Oblast	0	2	1	0
Kyiv city	37769049,2	12	7	0
Mykolaiv Oblast	0	1	0	0
Odesa Oblast	3247111,6	3	1	0
Poltava Oblast	740699,9	0	6	0
Rivne Oblast	415146,9	0	0	3
Sumy Oblast	885870	1	0	0
Ternopil Oblast	96538,8	2	0	0
Kharkiv Oblast	3939087,2	2	1	1
Kherson Oblast	48942,3	1	0	0
Khmelnyskyi Oblast	623591,7	0	0	0
Cherkasy Oblast	0	0	0	0
Chernivtsi Oblast	889,6	0	0	0
Chernihiv Oblast	41301,6	0	0	0

*Source: compiled by the authors based on [5, 16]

The dependent variable (*Output_high*), which characterizes the level of development of the high-tech sector, was defined as the volume of realized high-tech production at the regional level for the year 2023. An analysis of each region's share of the total volume of high-tech production in 2023 (fig. 1) reveals that innovation activity in Ukraine is extremely concentrated. For instance, the city of Kyiv alone accounts for almost two-thirds (63,88%) of the nation's total high-tech output. Dnipropetrovsk (6,67%) and Kharkiv (6,66%) oblasts also make a substantial, though considerably smaller, contribution. Meanwhile, this figure does not exceed 3% in the majority of regions and is zero in several oblasts, which highlights the acute problem of uneven innovation development.

For the econometric analysis, the independent variables reflecting the state of the innovation ecosystem at the individual administrative-territorial unit level were defined as the quantitative indicators of

existing facilities: science parks (SP), technology parks (TP) and innovation technology platforms (ITP).

Simultaneously, for the purpose of visualizing the overall landscape of territorial disparities and conducting a descriptive analysis, the 25 administrative-territorial units of the study were additionally grouped into five conventional macroregions based on a geographical principle (fig. 2).

Fig. 2 confirms that the Northern region, driven by the dominance of Kyiv city, accumulates over a third of all facilities (36,84%). The Western and Central regions hold approximately equal shares (21,05% each), whereas the contribution of the Southern (14,04%) and particularly the Eastern (7,02%) regions is considerably smaller.

All econometric estimations and diagnostic tests were performed using the Gretl software package.

A key methodological feature of the source data is the presence of a significant



Fig. 1. Share of Ukraine's regions in the total volume of realized high-tech production in 2023, %

Source: elaborated by the authors based on [16]

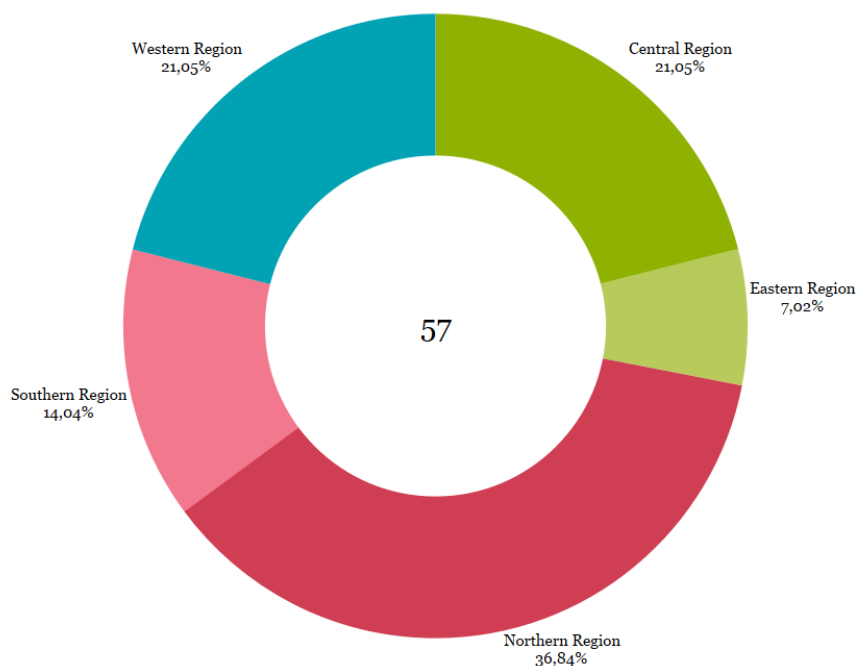


Fig. 2. Distribution of innovation infrastructure objects by macroregions of Ukraine in 2023, %
Source: elaborated by the authors based on [5]

number of zero values for the dependent variable, as high-tech production is absent in 5 of the 25 administrative-territorial units under study. This data structure renders the application of the standard ordinary least squares method to a logarithmized dependent variable inappropriate, as it would lead to the loss of these observations and, consequently, result in sample selection bias.

To obtain consistent and unbiased estimates, a Tobit model was chosen. This approach, based on the maximum likelihood method, is theoretically sound for analysing dependent variables that are censored at a certain level. It allows for the simultaneous assessment of a factor's impact on both the probability of observing a positive production volume and on its expected level.

The final specification of the model is as follows:

$$\text{Output_high}_i^* = \beta_0 + \beta_1 \text{SP}_i + \beta_2 \text{TP}_i + \beta_3 \text{ITP}_i + \varepsilon_i$$

where Output_high_i^* is a latent variable representing the potential production volume and the observed variable Output_high_i is equal to Output_high_i^* , if $\text{Output_high}_i^* > 0$, and 0 otherwise.

Before interpreting the estimated coefficients, a series of diagnostic tests were conducted to verify the model's adequacy and robustness. Firstly, a multicollinearity analysis using variance inflation factors showed that all values were significantly lower than the critical threshold of 10 (maximum VIF < 2.0), indicating the absence of this issue.

Secondly, a test for the normality of residuals indicated a deviation from the normal distribution. Additionally, given the high probability of heteroskedasticity in cross-sectional regional data, robust estimates from the quasi-maximum likelihood method were used to calculate standard errors and test coefficient significance. This approach is robust to both issues and ensures the reliability of statistical inferences even in the presence of non-normal residuals and non-constant variance.

Thirdly, the final validation stage involved a robustness check of the results against the influence of individual observations. The model was re-estimated on a subsample that excluded the observation

with the largest residuals (Kyiv city). The results showed that all key variables retained their sign and statistical significance. This indicates the reliability of the conclusions and the absence of undue influence from any single region on the overall result.

The estimation results of the final Tobit model are presented in table 2. Overall, the model is highly significant, which is confirmed by the likelihood-ratio test (p -value of the Chi-squared statistic < 0.001).

An analysis of the coefficients for the individual variables indicates that all three elements of the innovation ecosystem have a positive and statistically significant impact on the volume of high-tech production.

Science parks (SP) emerged as the most powerful driver. The coefficient for this variable is positive and statistically significant at the 0,1% level ($p < 0,001$). This underscores the critical importance of the close link between R&D activities, academia and the real sector for the generation of innovative products.

Innovation technology platforms (ITP) also have a strong impact, with significance at the 1% level. This confirms their effectiveness as platforms for commercializing technology and supporting innovative projects.

Technology parks (TP) demonstrate a significant positive effect at the 5% level, completing the overall picture of the innovation ecosystem and confirming their role in stimulating high-tech production.

The significant negative coefficient for the constant term reflects a conditional baseline level of production in the complete absence of the researched infrastructure facilities.

For a correct quantitative interpretation of the magnitude of the impact, marginal effects were calculated. The calculations showed that the creation of one additional science park, *ceteris paribus*, increases the expected volume of high-tech production in a region by an average of UAH 2 044 800. Similarly, one additional innovation technology platform increases this production by an average of UAH 677 320 and a technology park by UAH 575 150.

Therefore, the conducted econometric analysis has allowed for the quantitative confirmation of the hypothesis regarding the positive impact of the analysed components of the innovation ecosystem on the innovation-driven modernization of the regional economy. The obtained results indicate that developing a network of science, innovation and technology parks is an effective tool for stimulating high-tech production.

The key conclusion is the identification of science parks as the most influential element of the innovation ecosystem. This implies that state regional development policy should be primarily focused not merely on the creation of infrastructure facilities, but on ensuring their close ties with scientific and educational centres.

Table 2

Results of the tobit model estimation (n=25, QML standard errors)
Dependent variable: Output_high*

	<i>Coefficient</i>	<i>Std. error</i>	<i>z</i>	<i>p-value</i>
const	-2,02959e+06	688673	-2,947	0,0032
ITP	866672	315839	2,744	0,0061
SP	2,61639e+06	291735	8,968	<0,0001
TP	735932	293820	2,505	0,0123
Chi-squared(3)	126,4402	p-value		3,16e-27
Log-likelihood	-326,8490	Akaike criterion		663,6980
Schwarz criterion	669,7923	Hannan-Quinn criterion		665,3883

*Source: calculated by the authors

However, it is important to acknowledge that this study has certain limitations stemming from its use of cross-sectional data for a single year (2023). Firstly, this approach cannot control for unique, time-invariant unobserved regional characteristics, such as entrepreneurial culture or other institutional peculiarities. Secondly, the model does not account for the impact of other relevant time-varying factors, such as the volume of foreign direct investment into a region or specific market conditions during the studied year. Therefore, a promising avenue for future research is the transition to a panel data analysis, which would yield more reliable estimates of causal relationships and provide more robust recommendations for long-term public policy.

Conclusions. This research provides empirical confirmation of the hypothesis regarding the positive impact of the innovation ecosystem on the development of high-tech production in Ukraine's regions. It was established that science parks, technology parks and innovation technology platforms are drivers of this process. This finding demonstrates that the close "relationships" between the key "actors" of the innovation ecosystem, namely, scientific institutions and business, cultivated within science parks are crucial for the creation of innovative new

products. This result underscores the critical importance of prioritizing state support for science-oriented infrastructure that facilitates the transfer of knowledge and technology from academia to the real economy.

This study opens avenues for future research that can move beyond establishing the impact of the innovation ecosystem to understanding the mechanisms of its functioning and how to enhance its effectiveness. Research into the lifecycle and evolution of innovation ecosystems is crucial, as the current analysis is static and the tangible effects of creating innovation infrastructure are not instantaneous. The socio-economic impact of innovation infrastructure also needs to be assessed; in addition to production volume, it is important to investigate how the creation of science parks affects the labour market, demographic processes, the development of related industries and the overall investment attractiveness of a region. In the current context, research into the role of the innovation ecosystem in enhancing national resilience and defence capabilities is of particular relevance. A comprehensive answer to these questions will allow for a transition from general support for innovation to the development of a differentiated, flexible and evidence-based state policy, which is a key prerequisite for the successful modernization of Ukraine's economy.

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INNOVATION ECOSYSTEMS AND THE MODERNIZATION OF HIGH-TECH PRODUCTION AT THE REGIONAL LEVEL IN UKRAINE

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<https://doi.org/10.32342/3041-2137-2026-2-65-2>

Keywords: *innovation ecosystem, institutional change, high-tech production, regional development, innovation-driven modernization, innovation policy, post-war recovery*

JEL classification: *O38, R11, R58*

Amidst the new challenges facing Ukraine's economy, the problem of finding and implementing effective tools for structural modernization and the transition from a resource-based to a high-tech economic model has become a pressing strategic imperative. A key mechanism for this modernization is the formation of robust regional innovation ecosystems. According to established theoretical approaches, these ecosystems are not merely a collection of separate structural elements, but rather dynamic systems of interconnected economic and social actors, institutions and relationships that, through cooperation and competition networks, foster the creation of innovations, attract investment, and enhance economic competitiveness. The article contributes to the literature by providing a rare empirical assessment of ecosystem effectiveness in a country undergoing extreme external shocks and post-war transformation. The purpose of this paper is to quantitatively assess the impact of key infrastructural elements of these ecosystems (specifically, science parks, technology parks, and innovation platforms) on the volume of high-tech production across the regions of Ukraine.

The empirical analysis is based on statistical data for 25 regions of Ukraine for the year 2023. A significant methodological challenge arises from the nature of the dependent variable, as a substantial portion of regions (5 out of 25) report zero high-tech output. This data censoring renders standard Ordinary Least Squares regression models susceptible to sample selection bias. To obtain consistent and unbiased estimates, this study employs an econometric Tobit model, which is specifically designed to handle such censored data structures. The independent variables quantify the presence of the aforementioned infrastructural objects.

The results of the econometric analysis provide strong empirical support for the central research hypothesis: considered types of innovation infrastructure have a positive and statistically significant impact on the volume of high-tech production. The findings reveal a distinct hierarchy of influence among these elements. Science parks emerge as the most powerful driver, exhibiting the largest and most statistically significant positive effect. This result underscores their pivotal role in creating an effective environment for innovation generation by bridging the gap between academia and industry. While their impact is comparatively smaller, innovation technology platforms and technology parks also contribute substantially to the regional development of the high-tech sector, confirming their importance as valuable, complementary components of a comprehensive innovation ecosystem.

The study's conclusions offer significant theoretical and practical implications. Theoretically, the results empirically validate the core tenets of the innovation ecosystem framework, demonstrating that the effectiveness of infrastructure is contingent upon its ability to foster and institutionalize productive "relationships" between key "actors" (science institutions and business). The superior impact of science parks confirms that synergistic effects are most potent at the intersection of fundamental knowledge and its practical commercialization. From a policy perspective, these findings provide a crucial, evidence-based foundation for prioritizing state interventions. For a nation focused on post-

war economic recovery, the research suggests that innovation policy should be strategically directed towards cultivating deep, collaborative linkages rather than merely increasing the number of isolated infrastructural objects. This approach is critical for ensuring the efficient allocation of limited resources and achieving sustainable, innovation-driven modernization.

Дата надходження до редакції / Submitted: 18.08.25

Дата прийняття до публікації / Accepted: 29.01.26

Дата публікації / Published: 02.07.2026