

## Емерджентні ефекти розвитку інноваційних університетських екосистем

**Предметом дослідження** є процес формування емерджентних ефектів у розвитку інноваційних університетських екосистем, що включає взаємодію освітніх, наукових, підприємницьких та інституційних компонентів, а також механізми виникнення доданої цінності внаслідок їх синергетичної взаємодії.

**Метою дослідження** є обґрунтування сутності емерджентних ефектів та визначення особливостей їх прояву у розвитку інноваційних університетських екосистем з подальшим формуванням підходів до їх використання в управлінській практиці.

**Методи дослідження** є аналіз і синтез, системний підхід, порівняльний аналіз, індукція та дедукція, а також елементи структурно–функціонального аналізу складних соціально–економічних систем.

**Результати роботи:** розкрито сутність інноваційних університетських екосистем як складних динамічних систем; визначено ключові елементи та характер їх взаємодії; обґрунтовано природу емерджентних ефектів як результату нелінійних взаємозв'язків; систематизовано основні типи емерджентних ефектів та механізми їх виникнення; встановлено роль мережевих взаємодій у формуванні інноваційного потенціалу університетів; окреслено напрями підвищення ефективності функціонування університетських екосистем.

**Галузь застосування результатів.** Отримані результати можуть бути використані: органами державного управління для формування політики розвитку інноваційних екосистем; у закладах вищої освіти для вдосконалення стратегій розвитку та підвищення ефективності взаємодії з бізнесом; у науково–дослідних установах для активізації інноваційної діяльності; у практиці управління для підвищення результативності функціонування університетських екосистем.

**Висновки.** У ході дослідження встановлено, що емерджентні ефекти є ключовим фактором розвитку інноваційних університетських екосистем і визначають їх здатність до саморозвитку та генерації доданої цінності. Ефективність функціонування таких систем залежить від якості взаємодії між їх елементами та рівня інтеграції освітніх, наукових і підприємницьких процесів. Врахування емерджентних ефектів дозволяє підвищити обґрунтованість управлінських рішень та забезпечити стійкий розвиток закладів вищої освіти.

**Ключові слова:** університетські екосистеми, емерджентні ефекти, інноваційний розвиток, академічне підприємництво, синергетика, мережеві взаємодії, інтелектуальний капітал, економіка знань.

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## Emergent effects of the development of innovative university ecosystems

**The subject of the study** is the process of formation of emergent effects in the development of innovative university ecosystems, which includes the interaction of educational, scientific, entrepreneurial and institutional components, as well as the mechanisms of added value generation as a result of their synergistic interaction.

**The purpose of the study** is to substantiate the essence of emergent effects and determine the features of their manifestation in the development of innovative university ecosystems with the subsequent formation of approaches to their use in management practice.

**The research methods** are analysis and synthesis, a systems approach, comparative analysis, induction and deduction, as well as elements of structural and functional analysis of complex socio–economic systems.

**Results of the work:** the essence of innovative university ecosystems as complex dynamic systems is revealed; the key elements and the nature of their interaction are identified; the nature of

*emergent effects as a result of nonlinear relationships is substantiated; the main types of emergent effects and the mechanisms of their occurrence are systematized; the role of network interactions in the formation of the innovative potential of universities is established; directions for increasing the efficiency of university ecosystems are outlined.*

**Field of application of the results.** *The results obtained can be used: by state administration bodies to form a policy for the development of innovative ecosystems; in higher education institutions to improve development strategies and increase the efficiency of interaction with business; in research institutions to activate innovative activity; in management practice to increase the efficiency of university ecosystems.*

**Conclusions.** *The study found that emergent effects are a key factor in the development of innovative university ecosystems and determine their ability to self-develop and generate added value. The effectiveness of the functioning of such systems depends on the quality of interaction between their elements and the level of integration of educational, scientific and business processes. Taking into account emergent effects allows to increase the validity of management decisions and ensure the sustainable development of higher education institutions.*

**Keywords:** *university ecosystems, emergent effects, innovative development, academic entrepreneurship, synergy, network interactions, intellectual capital, knowledge economy.*

**Problem statement.** The development of higher education institutions is taking place in the context of the increasing role of innovation, digital transformations and integration into global knowledge networks, which is changing traditional approaches to organizing their activities. Universities increasingly function not as isolated institutions, but as components of innovation ecosystems, within which interaction between education, science, business and the state is formed. Such interaction generates new effects that are not reduced to the sum of individual results of the participants' activities, but manifest themselves as emergent properties of the system. At the same time, in the practice of managing the development of universities, these effects remain insufficiently taken into account, since they are difficult to formalize within traditional economic approaches. Existing research is mostly focused on the analysis of individual components of innovation activity, without paying sufficient attention to systemic relationships and their nonlinear nature. This limits the possibilities of adequately assessing the potential of university ecosystems and hinders the formation of effective strategies for their development.

The relevance of the study is due to the need to deepen the theoretical understanding of emergent effects in the development of innovative university ecosystems and to substantiate approaches to their identification and use in management practice. Taking into account such effects allows expanding the tools of analysis, increasing the effectiveness of management decisions, and ensuring

more effective functioning of higher education institutions in a dynamic environment.

**Analysis of recent research and publications.** In scientific research, the development of university ecosystems is considered through the prism of innovation, entrepreneurial universities, and the integration of education, science, and business. At the same time, issues of emergent effects are mostly covered within the framework of the theory of complex systems and are only partially applied to the sphere of higher education [1–6]. Existing publications do not provide a holistic view of the mechanisms of the emergence of such effects in university ecosystems, which necessitates further research in this area.

**Presentation of the main material.** The development of innovative university ecosystems should be considered as a process of forming a complex multi-level system of interactions between key stakeholders, among which higher education institutions, business structures, state institutions and infrastructure elements of innovation activity play a leading role. Unlike traditional models of university functioning, where internal organizational logic dominates, the ecosystem approach assumes openness, network interaction and the ability to self-organize. In such conditions, the results of university activities are formed not only under the influence of individual resources or management decisions, but also due to the interaction between elements of the system, which generates emergent effects. These effects manifest themselves in the form of accel-

eration of innovation processes, increased quality of scientific results, increased efficiency of technology transfer and formation of new business models. An important sign of emergence is that the results obtained exceed the total effect of the functioning of individual components.

To systematize the key elements of the innovative university ecosystem and their functional purpose, it is advisable to present them in the form of a generalized structure (Table 1).

The formation of emergent effects in such a system occurs as a result of the synergistic interaction of the specified elements. In particular, the combination of scientific developments with entrepreneurial activity creates conditions for the rapid commercialization of innovations, while the integration of educational programs with real business processes contributes to improving the quality of specialist training. The quantitative interpretation of emergence can be presented as the excess of the integral result of the functioning of the system over the sum of the results of its individual components. This allows us to formalize the emergent effect as an additional component of efficiency that arises as a result of interaction. For a deeper understanding of the manifestations of emergent effects in the development of university ecosystems, it is advisable to consider their main types and mechanisms of formation (Table 2).

Thus, emergent effects are a key factor in increasing the efficiency of innovative university eco-

systems. Taking them into account allows us to move from the analysis of individual indicators to the study of systemic relationships, which opens up new opportunities for improving the management of the development of higher education institutions. The further development of innovative university ecosystems is associated with the deepening of inter-sectoral interaction and the transition from linear to network models of value creation. In such conditions, the university ceases to be only a generator of knowledge and is transformed into a center for coordinating the flows of information, resources and innovative initiatives. This changes the logic of management, which is increasingly focused on supporting horizontal connections, flexibility of organizational structures and rapid response to changes in the external environment. An essential characteristic of such ecosystems is the presence of self-reinforcing effects, when the results of previous interactions create the prerequisites for further growth. For example, successful startups that arise within the university form new funding channels, increase the reputation of the institution and stimulate the attraction of new participants to the ecosystem. As a result, a critical mass of innovative activity accumulates, which enhances the overall dynamics of development. At the same time, the functioning of such systems is accompanied by certain imbalances, in particular, uneven distribution of resources, information asymmetry and different speeds of devel-

**Table 1. Structure of the innovative university ecosystem**

System element	Content	Functional purpose	Result
Educational block	training, educational programs	competency development	human capital development
Scientific block	research, publications, projects	knowledge generation	innovative results
Entrepreneurship block	startups, incubators, technology transfer	commercialization	added value creation
Institutional block	public policy, regulation	coordination and support	operational stability
Infrastructure block	technological parks, hubs, laboratories	resource provision	efficiency improvement

Source: proposed by the authors

**Table 2. Types of emergent effects in university ecosystems**

Effect Type	Characteristics	Mechanism of occurrence	Mechanism of occurrence
Synergetic	exceeding the total result	interaction of elements	interaction of elements
Cognitive	accumulation of knowledge	information exchange	information exchange
Institutional	coordination of actions	regulatory support	regulatory support
Economic	increase in income	commercialization	commercialization
Network	economy of scale	expansion of connections	expansion of connections

Source: proposed by the authors

opment of individual subsystems. This requires the introduction of coordination tools that ensure the consistency of actions of participants and prevent loss of efficiency. Institutional support mechanisms that form the rules of interaction and create conditions for the stable functioning of the ecosystem are of particular importance.

In the context of quantitative analysis, the development of university ecosystems can be represented as a process of accumulation of interaction effects that are nonlinear. This means that even minor changes in one of the elements of the system can lead to significant transformations in its overall state. This property enhances the significance of management decisions aimed at supporting key interaction nodes that provide the maximum multiplicative effect.

Therefore, further research into emergent effects requires a combination of qualitative analysis of relationships with quantitative assessment methods, which allows for more accurate identification of sources of growth and determination of directions for increasing the efficiency of functioning of university ecosystems.

The further development of university ecosystems is associated with the formation of complex configurations of interactions, in which not only available resources play a decisive role, but also the ability of the system to redistribute and effectively use them. In this context, it is not the number of ecosystem elements that is important, but the quality of the connections between them, which determines the speed of transformation of knowledge into practical results. One of the characteristic features of such systems is the emergence of points of concentration of activity, where intensive accumulation of innovative potential occurs. These can be research centers, startup hubs or interdisciplinary platforms that act as catalysts for change. Their functioning contributes to the reduction of time lags between the creation and implementation of new ideas, which, in turn, increases the overall efficiency of the ecosystem.

At the same time, the strengthening of the relationships between the elements leads to an increase in the complexity of the system, which complicates its management. In such conditions, traditional administrative approaches are insufficient, since they do not take into account the multi-vector nature of processes and the high level of their interdependence. This necessitates the tran-

sition to adaptive management models focused on maintaining a balance between the autonomy of individual elements and the coherence of their actions. In addition, an important aspect is the ability of university ecosystems to recover from external influences. The stability of such systems is formed due to the diversification of resource sources, the availability of alternative channels of interaction and the flexibility of organizational structures. This allows maintaining functionality even in the event of disruption of individual connections or changes in operating conditions. Thus, further understanding of the development of innovative university ecosystems requires taking into account not only quantitative parameters, but also structural characteristics of interaction, which determine the system's ability to generate new effects and maintain sustainable development in a changing environment.

### Conclusions

Considering innovative university ecosystems as complex dynamic systems allows us to interpret the results of their functioning differently. It was found that the key development results are formed not so much due to individual resources or areas of activity, but due to the nature of interactions between the elements of the system. It is these interactions that cause the emergence of emergent effects that determine the ecosystem's ability to self-develop and generate added value. The study showed that emergent effects manifest themselves through the acceleration of innovation processes, increasing the effectiveness of knowledge transfer, and the formation of new organizational and business models. Their emergence is associated with the concentration of activity in key interaction nodes, as well as with the strengthening of network connections that ensure the exchange of resources and information. At the same time, the increase in the complexity of the system is accompanied by the need to adapt approaches to management, which should take into account the nonlinear nature of development. The results obtained indicate that the effectiveness of the functioning of university ecosystems depends on the ability to ensure a balance between the autonomy of individual elements and the coherence of their interaction. Of particular importance are mechanisms for supporting structural flexibility and stability, which allow the system to maintain integrity in the event of changes in the external environment.

The generalization of the analysis provides grounds to argue that taking into account emergent effects opens up new opportunities for improving approaches to the development of universities, allows for more accurate identification of sources of growth, and increases the validity of management decisions in the field of higher education.

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