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HUMAN CAPITAL AND DIGITAL INFRASTRUCTURE AS DETERMINANTS OF UNEVEN KNOWLEDGE ECONOMY FORMATION IN UKRAINIAN REGIONS

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Abstract

The article investigates human capital and digital infrastructure as key determinants of uneven knowledge economy formation in Ukrainian regions. Mechanisms of interdependence between human resources qualification and regional digital environment are revealed. A typology of Ukrainian regions by levels of human capital and digital infrastructure development is constructed. Persistent regional disparities and their structural and situational drivers — including the destructive impact of armed aggression — are identified. A set of differentiated regional policy measures aimed at overcoming these disparities is proposed.

Keywords: human capital, digital infrastructure, knowledge economy, regional development, digital divide, regional disparities, digital transformation.

INTRODUCTION

Spatial unevenness of development is one of the fundamental regularities of the market economy. In the context of the transition to a knowledge economy, this unevenness acquires new dimensions and reproduction mechanisms. If in the industrial era regional disparities were determined by the availability of natural resources and transport accessibility, then in post-industrial conditions human capital and digital infrastructure become the leading factors of regional differentiation [7].

For Ukraine, the problem of regional differences in human capital development and digital infrastructure is particularly acute: the country entered the phase of digital transformation with significant structural imbalances between regions, inherited from the Soviet past and deepened during the years of independence. Russia's armed aggression after 2022 inflicted additional, asymmetric blows on regional human capital systems and digital infrastructure, exacerbating an already complex situation [2; 14].

The aim of the article is to investigate human capital and digital infrastructure as determinants of uneven knowledge economy formation in Ukrainian regions, to identify spatial patterns and factors of regional differentiation, and to substantiate measures of corresponding regional policy.

The object of the study is the regional systems of human capital and digital infrastructure of Ukraine; the subject is the patterns and mechanisms of their impact on the unevenness of regional knowledge economy formation.

The methodological basis of the study comprises comparative analysis, typologization, the cartographic method and statistical analysis methods. The information base consists of data from the State Statistics Service of Ukraine, reports of the Ministry of Digital Transformation [6], OECD and World Bank materials

[9; 10; 17], as well as research results of domestic and foreign scholars.

1. Human capital as a determinant of regional knowledge economy: theoretical foundations and measurements

The concept of human capital developed by G. Becker [1] and T. Schultz [13] gained a new dimension in the theory of the knowledge economy: knowledge and competencies were transformed from one of the components of human capital into its central element. R. Lucas [4] and P. Romer [12] theoretically substantiated that the accumulation of human capital is the driver of endogenous economic growth and generates external effects (externalities) that are amplified in spatial clusters.

In the regional dimension, the quality of human capital is determined by the interaction of several factors: the educational level of the population, the employment structure, the concentration of research personnel, the mobility of qualified specialists and their opportunities for lifelong learning. For the regional knowledge economy, what matters is not simply the availability of highly qualified personnel, but their retention in the region and productive engagement in knowledge-innovation processes [2; 16].

A significant methodological challenge is the complexity of measuring human capital at the regional level. The most commonly used indicators are: the share of population with higher education, the number of researchers per 1,000 employed, expenditures on education and training (relative to GRP), and human development indices. Each of these indicators reflects only a single dimension and does not provide a complete picture of regional human capital. This article proposes an aggregated assessment based on a combination of four indicators (Table 1).

Table 1

Comparative indicators of human capital and digital readiness of Ukrainian regions (author's calculations based on State Statistics Service and Ministry of Digital Transformation data, 2021–2022)

Region type	Share of employed with higher education, %	Researchers per 1,000 employed	Digital Readiness Index (0–1)	IT company density (per 10,000 pop.)
Knowledge Leaders (Kyiv, Lviv, Dnipro)	42–48	8.2–12.1	0.68–0.82	9.4–14.2
Potential Leaders (Odesa, Vinnytsia, Poltava)	32–38	4.1–6.8	0.45–0.62	3.8–6.1
Digital Outsiders (Kirovohrad, Rivne, Volyn, etc.)	24–30	1.8–3.2	0.28–0.41	0.9–2.3
Militarily destructured (Donetsk, Luhansk, Zaporizhzhia, etc.)	n/a	n/a	disrupted	disrupted

* Data prior to the full-scale invasion; 2023–2024 statistics are incomplete due to hostilities.

The data in Table 1 clearly demonstrate a significant gap between leading and peripheral regions. The gap in the share of employed with higher education between Kyiv and agrarian regions reaches 2.1 times, while for the digital readiness index it is 2.5 times. These figures indicate that the digital divide amplifies and reproduces the unevenness of human capital, forming a closed loop of regional polarization [11].

2. Digital infrastructure as a spatial factor of the knowledge economy

Digital infrastructure is a necessary environment for the functioning of the knowledge economy: it provides access to information, enables distance education and work, reduces transaction costs of knowledge exchange, and creates conditions for the development of the IT industry and digital services [3; 9]. In the regional dimension, digital infrastructure plays the role of

a "spatial equalizer" — it is potentially capable of reducing the significance of geographic peripherality and bringing remote regions closer to knowledge generation centres.

However, empirical data show that this equalizing potential is far from being realized automatically. Studies of the effects of broadband internet access in various countries show that access to the network alone increases rather than decreases regional inequality if it is not accompanied by adequate human capital and an institutional environment [5; 11]. In other words, digital infrastructure is a necessary but not sufficient condition: its effectiveness for the formation of regional knowledge economy depends on the ability of the population and economic entities to use it.

Table 2

Disparities in digital infrastructure development between urban and peripheral regions of Ukraine

Indicator	Kyiv	Kharkiv	Lviv	Agrarian periphery (average)
Broadband internet penetration, %	89	78	74	41–52
4G/LTE mobile network coverage, %	96	89	87	55–68
Share of e-services users, %	67	54	59	22–34
IT company density (per 10,000 pop.)	14.2	11.8	10.3	0.9–2.3
Average Internet speed, Mbps	82	61	68	18–28

The data in Table 2 confirm significant disparities in digital infrastructure development. Particularly striking is the gap in IT company density — almost an order of magnitude greater in leading cities compared to peripheral regions. This explains the concentration of the IT industry — one of the key sectors of the knowledge economy — in several large cities (Kyiv, Kharkiv, Lviv, Dnipro, Odesa), which was observed before the full-scale invasion [6; 15].

Fundamentally important is also the issue of qualitative differentiation of digital infrastructure: not merely the availability of internet connection, but speed, reliability, cybersecurity, accessibility of cloud

services and data centres. By these parameters, the regional gap is even greater than for basic access [9].

3. Interaction of human capital and digital infrastructure in the formation of regional knowledge systems

Human capital and digital infrastructure are not independent determinants of the regional knowledge economy: they are in a relationship of complementarity and mutual reinforcement. On the one hand, developed digital infrastructure increases the productivity of human capital, expands access to education and knowledge, and opens new employment opportunities in knowledge-intensive sectors. On the other hand, the

mere availability of digital infrastructure is insufficient without human capital capable of using it effectively.

This complementarity generates the "cumulative causation effect" (G. Myrdal [8]): regions with developed human capital and digital infrastructure attract additional investment, qualified migrants and new businesses, which further strengthens their positions. In contrast, lagging regions face the outflow of qualified personnel and reduced investment, which consolidates their peripheral status. Thus, without active regional and national policy intervention, market mechanisms amplify rather than overcome the uneven formation of the knowledge economy [11; 18].

The situation in Ukraine after 2022 has become significantly more complex: the full-scale armed aggression dealt an asymmetric blow to the regional systems of human capital and digital infrastructure. Regions with significant human capital (Kharkiv, Zaporizhzhia, Donetsk, Kherson, Luhansk, Mykolaiv, Sumy, Chernihiv oblasts) suffered the greatest losses due to hostilities, evacuation of the population and destruction of infrastructure, and their knowledge potential relocated either to safer Ukrainian regions or abroad [2; 14].

4. Typology of Ukrainian regions by human capital and digital infrastructure development

Based on the analysis performed, a typology of Ukrainian regions is proposed according to the combination of development levels of human capital (HC) and digital infrastructure (DI):

Type 1. "Knowledge Leaders" (high HC + high DI): Kyiv city, Kharkiv (before 2022), Lviv, Dnipropetrovsk oblasts. These regions are characterized by the concentration of universities, scientific institutions, IT companies and qualified specialists. They are the nuclei of regional innovation systems and form "attraction points" for human capital [7; 16].

Type 2. "Potential Leaders" (medium HC + medium/high DI): Odesa, Zaporizhzhia (before 2022), Vinnytsia, Poltava oblasts. These regions have the necessary foundation for knowledge economy development but have not yet realized their potential due to institutional and structural constraints [11].

Type 3. "Digital Outsiders" (low HC + low DI): A significant part of agrarian oblasts — Kirovohrad, Cherkasy, Ternopil, Rivne, Volyn, Chernivtsi oblasts. These are characterized by human capital outflow, weak digital infrastructure and the dominance of low-technology sectors [18].

Type 4. "Militarily Destructured" (disrupted HC + destroyed DI): Donetsk, Luhansk, Zaporizhzhia, Kherson, Mykolaiv, partially Kharkiv, Sumy, Chernihiv oblasts. This typological group is specifically Ukrainian and has no analogues in foreign classifications [2; 14].

The proposed typology allows for the differentiation of regional policy measures depending on the combination of human capital and digital infrastructure development levels, avoiding template approaches that are identical for fundamentally different regional situations.

5. Directions of regional policy for eliminating disparities

The identified patterns allow us to substantiate the principles and specific instruments of regional policy aimed at overcoming disparities in human capital and digital infrastructure development:

The first principle is differentiation: measures should correspond to the type of region (according to the proposed typology), rather than being uniform for the entire country. For "knowledge leaders", relevant measures include talent retention and scaling of innovation ecosystems; for "digital outsiders" — basic digitalization and educational programs; for "militarily de-structured" regions — infrastructure restoration and the return of evacuated human capital [2; 10].

The second principle is complementarity of investments: investments in digital infrastructure must necessarily be accompanied by digital literacy programs and skills development, otherwise their effect for the knowledge economy will remain minimal. Isolated investments in "hardware" without the corresponding "human" component are ineffective [10; 11].

The third principle is resilience: in the context of wartime and post-war conditions, the capacity of regional knowledge systems to maintain functioning and recover from destructive shocks becomes critically important. This requires the decentralization of critical digital infrastructure nodes, the formation of reserve capacities, and mechanisms for preserving and returning human capital [2; 15].

Conclusion

Human capital and digital infrastructure are inter-related and mutually reinforcing determinants of the regional knowledge economy. Their complementary nature determines the effect of cumulative amplification of regional disparities: successful regions increase their advantages, while lagging ones consolidate their weaknesses.

In Ukraine, these disparities have a dual character: on one hand, they are a structural legacy of the past (concentration of scientific and educational institutions in a few large cities), and on the other — they acquired new manifestations as a result of armed aggression, which asymmetrically struck regions with significant knowledge potential [2; 14].

The proposed typology of regions and the substantiated principles of regional policy create a practical foundation for differentiated, complementary and resilient approaches to supporting human capital and digital infrastructure development in different types of Ukrainian regions [10; 18].

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