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INVESTMENT ASSESSMENT OF HUMAN CAPITAL

The investment assessment of human capital within the national innovation system is a key precondition for Ukraine's economic resilience and competitiveness amid digital transformation, the challenges of martial law, and population migration. As the traditional approaches are mostly based on indicators of formal education, work experience, and qualifications, and innovative indicators are difficult to analyze at the macro level, an important step in improving such assessment is a comprehensive approach. It should combine cost, income, and market methods with indicators of performance, creative abilities, and human adaptability in educational, market, and scientific environments in conditions of unpredictable change. The hypothesis is put forward that a comprehensive investment assessment, combining traditional quantitative indicators with innovative qualitative ones, increases the effectiveness of the distribution of investment resources in enterprises, institutions, and organizations and the ability of experts to generate ideas and commercialize innovations. Methods of a systematic approach, structural-logical and empirical analysis, statistical data and interpretation of results were used. According to the data obtained for Ukraine, in the context of increasing digitalisation, the share of education expenditure in GDP is gradually increasing, particularly in the field of IT specialist training. At the same time, the country faces constant demographic and migration losses for various reasons (economic and political instability, the COVID-19 pandemic, full-scale war). The latter are largely responsible for the reduction in the number of higher education and postgraduate

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ІНВЕСТИЦІЙНА ОЦІНКА ЛЮДСЬКОГО КАПІТАЛУ

Інвестиційна оцінка людського капіталу у національній інноваційній системі є ключовою передумовою економічної стійкості та конкурентоспроможності України в умовах цифрової трансформації, викликів воєнного стану й міграції населення. Оскільки традиційні підходи здебільшого базуються на показниках формальної освіти, досвіду роботи й кваліфікації, а інноваційні показники важко аналізувати на макрорівні, важливим кроком удосконалення такої оцінки є комплексний підхід. Він має поєднувати витратний, дохідний та ринковий методи з індикаторами результативності, креативних здібностей та адаптивності людини в освітньому, ринковому та науковому середовищі в умовах непередбачуваних змін. Висунуто гіпотезу, що комплексна інвестиційна оцінка, що поєднує традиційні кількісні показники з інноваційними якісними, підвищує результативність розподілу інвестиційних ресурсів на підприємствах, в установах та організаціях і спроможність фахівців генерувати ідеї й комерціалізувати інновації. Використано методи системного підходу, структурно-логічного, емпіричного аналізу, статистичні дані та інтерпретації результатів. Згідно з отриманими даними по Україні, в умовах посилення цифровізації частка видатків на освіту у ВВП поступово зростає, зокрема в галузі підготовки ІТ-спеціалістів. Водночас країна стикається з постійними демографічними та міграційними втратами з різних причин (економічна й політична нестабільність, пандемія COVID-19, повномасштабна війна). Останні значною мірою спричиняють скорочення контингенту закладів вищої освіти та

institutions, which leads to a cyclical decline in the scientific productivity of the population. Furthermore, high unemployment in the first year of martial law and incomplete recovery of employment pose risks to the reproduction of innovative personnel. Under such conditions, the state's investment policy should focus on early and continuous investment in education, using tools to attract and retain professionals. The results of the research indicate the need to align educational programs with the needs of science and IT in the direction of developing technology transfer infrastructure and a startup ecosystem, which will lead to an increase in the number of jobs and, consequently, enable investment support for the post-war reconstruction of Ukraine from a special fund financed by individuals and legal entities.

Keywords: human capital, investment assessment, national innovation system, digital transformation, education, labor market.

аспірантури, що призводить до циклічного збою у науковій продуктивності населення. Крім того, пікове безробіття в перший рік воєнного стану й неповне відновлення зайнятості формують ризики для відтворення інноваційних кадрів. За таких умов інвестиційна політика держави має бути спрямована на пріоритет ранніх і безперервних інвестицій у галузь освіти із застосуванням інструментів повернення та утримання талантів. Результати дослідження дозволяють зробити висновок про необхідність узгодження освітніх програм з потребами галузей науки та IT у напрямі розвитку інфраструктури трансферу технологій і стартап-екосистеми, що зумовить збільшення кількості робочих місць та уможливить інвестиційну підтримку повоєнної відбудови України зі спеціального фонду за кошти фізичних та юридичних осіб.

Ключові слова: людський капітал, інвестиційна оцінка, національна інноваційна система, цифрова трансформація, освіта, ринок праці.

JEL Classification: E24, I26, J24, O15, O32.

Introduction

The current stage of the world economy is determined by the dominance of the knowledge paradigm, within which human capital forms sustainable competitive advantages. In Ukraine, demographic and migration shocks caused by a full-scale war and a shortage of qualified personnel due to gaps in educational and scientific chains require an assessment of the priority of investments in human capital development. Given the limited resource capabilities and the country's need for post-war reconstruction, it is advisable to develop a methodology for investment assessment of human capital aimed at comparing investment alternatives in terms of returns and risks in synchronizing the levels of education, employment and innovative activity of the population. Existing approaches focused on formal education do not sufficiently take into account digital competencies, social mobility and human creativity. In this context, it is necessary to develop a comprehensive approach to assessing human capital, combining cost, income and market approaches with innovation indicators. This approach will make it possible to assess the effectiveness of the state's investment policy in the field of technology transfer development through the return and/or retention of highly qualified personnel and the formation of an innovative startup ecosystem within the framework of its harmonization with European standards.

The theoretical foundations of human capital research are laid in the works of Nobel laureates, who substantiated the concept of investment in human development as the basis of economic growth. If Schultz (1961, March) considered education as a form of capital that generates future income, emphasizing the importance of investment in training and skills development, then Becker (1994) expanded this concept, including professional experience,

skills and abilities that increase labor productivity in human capital. Modern research on human capital in the national innovation system is focused on the creative and entrepreneurial competencies of the individual. If in combination with creative abilities and innovative activity, human capital becomes the main factor of technological change (Petrova & Pereira, 2024), then in the competence dimension in the context of Industry 4.0 – it requires new assessment procedures (Kolot et al., 2023). A review of cost, income, and market approaches to investment assessment demonstrates fragmentation and methodological divergence in taking into account qualitative indicators of human capital and external factors influencing its development (Nochka, 2022). Accordingly, investments in human capital are becoming a key factor in the productivity of the population and the country's economic growth (Panchyshyn et al., 2024).

The legal framework of the subjects of the national innovation system determines the requirements for the coordination of educational and scientific, investment and innovation policies (Ivanova, 2024). At the same time, based on business strategies and entrepreneurial paradigms of global integration, knowledge commercialization channels are formed, which create demand for highly qualified personnel (Prodius et al., 2020). In a comparative context, it is important to analyze public investments in education in developed countries (Dumanska, 2021, March 8), which serve as a benchmark for Ukrainian priorities for innovative investments in human capital.

The United Nations Development Program emphasizes the importance of forming an institutional structure for investment policy that would ensure the effective use of resources to achieve sustainable development goals and national security (UNDP Ukraine, 2023, October 27). The Ukrainian Institute for the Future emphasizes the need to develop human capital to ensure Ukraine's competitiveness in the global economy (UIF, 2021, June 18).

The problem of investment valuation of human capital has become particularly relevant in the context of martial law, when Ukraine faced a mass migration of qualified personnel. The results of a study of the situation of Ukrainian migrants in Poland indicate significant losses of human capital, which requires the development of effective mechanisms for its preservation and development (Narodowy Bank Polsky, 2023).

The issue of a comprehensive investment assessment of human capital remains insufficiently researched, which would allow, at the macro level of the national innovation system, to integrate traditional indicators according to the cost, income and market approaches with innovation indicators, each group of which determines the qualities of human capital, in particular, effectiveness in learning, the ability to generate ideas and adaptability in the educational, market and scientific space.

The aim of the research is to develop and empirically verify a comprehensive approach to the investment assessment of human capital in the national innovation system on the basis of the integration of cost, income and market approaches with the main qualitative indicators of the innovative development of human capital using the example of Ukraine.

Research hypothesis is that a comprehensive investment assessment of human capital within the framework of the integration of cost, income and market approaches with indicators of innovative development provides a more accurate diagnosis of the state of the national innovation system, the results of which provide a justification for the feasibility of investments. This correspondence is confirmed by the trends for 2015–2024, when the contingent of higher education institutions and young scientists is gradually decreasing, despite the increase in the share of education expenditures, where the training of IT specialists is especially activated. In such a situation, the publication activity of scientists is subject to unstable fluctuations, when a sudden increase in the unemployment rate and migration losses in crisis situations (economic and political instability, COVID-19 pandemic, full-scale war) significantly hinders the full reproduction of scientific and innovative personnel. Therefore, the combination of traditional and innovative indicators is more useful for investment policy than using each group of indicators separately. Such a combination increases the feasibility of investments in increasing the capacity of scientific personnel to generate new ideas, and innovative personnel to commercialize research and innovation results.

The research methodology is based on the application of the system: approach method is applied for identifying the relationship between education, labor market and science as factors in the formation of the national innovation system; the structural-logical method is important to determine a comprehensive approach to the investment assessment of human capital in the national innovation system in the context of the integration of traditional (share of education expenditures in GDP, number of entrants and students, average wage, unemployment rate, migration) and innovative indicators (number of graduates with higher education, share of IT experts, number of PhD students; number of published scientific papers in the Scopus database); the empirical analysis method is used to collect and process actual indicators of human capital in the national innovation system; the statistical data method is important to compare official statistical series of traditional and innovative indicators of human capital of Ukraine for 2015-2024; method of interpreting results are used when coordinating the goals of the investment policy of the state and society with the provision of recommendations for early and continuous investments in the fields of education, science and IT, which will contribute to the development of technology transfer and the startup ecosystem.

The main part of the article has four sections: in the first, the conceptual framework and analysis of the organizational and institutional principles of investment assessment of human capital in the national innovation system are considered; in the second section, a comprehensive approach to investment assessment of human capital in the national innovation system is substantiated in the context of integrating cost, income and market approaches with innovative indicators of performance, creative abilities and adaptability of a person in conditions of crisis changes; in the third section, the general state of human capital of Ukraine is analyzed according to traditional and innovative indicators for 2015–2024, the results

of which revealed problems of reproduction of scientific and innovative personnel in conditions of digitalization of the economy under the influence of population migration to the national innovation system; The fourth chapter highlights the challenges and prospects for the development of human capital in Ukraine and formulates practical recommendations for improving the investment policy of human capital development by the state and society.

1. Theoretical foundations of the place of human capital in the national innovation system

The concept of human capital has gone through a long evolution from understanding it as a simple set of knowledge, skills and abilities to a complex phenomenon that encompasses creative abilities, adaptability, entrepreneurial competencies and innovative potential of the individual. The scientist Schultz (1961, March) substantiated the idea that investments in education and training create a special type of capital that generates future incomes similar to physical capital in his work. This approach revolutionized the understanding of the role of man in economic development, shifting the emphasis from labor resources to human capital as an active factor of production.

For his part, Becker (1994) expanded the Schultz concept, including professional experience, health, motivation and other characteristics that affect labor productivity. The scientist attached particular importance to formal and informal education, training in the workplace, which form the specific skills of the employee. This concept has become the theoretical basis for understanding investment in human development as a strategic direction of economic policy.

Modern theories of human capital emphasize its role in innovation processes and the formation of a knowledge economy. Human capital is considered not only as a set of knowledge, skills and abilities, but as a dynamic system of competencies that ensures a person's ability to generate new ideas, adapt to changes and create innovative solutions (Kolot et al., 2023). This is especially important in the context of national innovation systems, where human capital is a key element of the innovation ecosystem.

The national innovation system is a set of interconnected institutions, organizations and policy instruments that ensure the generation, diffusion and use of innovations in the country's economy (Ivanova, 2024). In this system, human capital performs the function of generating new ideas through scientific research and development, facilitating the transfer of knowledge between different sectors of the economy, where the results of innovative solutions are subsequently commercialized through entrepreneurial activity, ensuring the adaptation of the economy to technological changes.

The effectiveness of the national innovation system largely depends on the quality of human capital, its structure and opportunities for innovative development. The United Nations Development Program emphasizes the importance of creating a favorable institutional environment for the

development of human capital, including the system of education, scientific research and support for entrepreneurship in innovative activities (UNDP Ukraine, 2023, October 27). Of particular importance is the formation of a human capital development policy that would ensure consistency between the needs of the national innovation system and the capabilities of the education and science system.

The investment approach to human capital involves considering expenditures on education, training, healthcare, and skills development as investments that generate future income for the individual and society as a whole (Panchyshyn et al., 2024). Within the framework of the national innovation system, investments in human capital have a particularly high return, as they are aimed at increasing the innovative activity of enterprises, institutions, and organizations where innovative products are sold, which contributes to the development of high-tech industries.

The specificity of human capital in the national innovation system is its ability to self-growth through learning, accumulation of experience, and interaction with other knowledge carriers. Such specificity creates a synergy effect, when the total return on human capital exceeds the sum of individual contributions (Prodius et al., 2020). In this context, the clustering of innovation activities within the framework of the establishment of scientific and educational complexes, with the aim of strengthening cooperation between universities, scientific institutions and business companies, determines the maximization of the effect of investments in human capital.

Formal education remains the basic component that provides fundamental knowledge and analytical skills necessary for innovative activities at enterprises, institutions and organizations. However, in modern conditions, there is a growing need for informal education, self-education and continuous learning as factors influencing the acquisition of skills in the field of IT, in particular project management, the totality of which forms a person's ability for interdisciplinary cooperation against the background of mastery of information and communication technologies (ICT). Here, meta-skills play a significant role, thanks to which one can quickly master new knowledge and adapt to changes in the technological environment, which consolidates in a person the creative abilities to generate original ideas, non-standard thinking and search for innovative solutions to solve complex problems (Petrova & Pereira, 2024). These competencies are especially necessary at the stages of conceptualizing innovative projects and developing fundamentally new products.

The development of creativity requires specific learning approaches that include encouraging experimentation, tolerance for failure, and support for unconventional ideas, the ability to commercialize which requires the creation of new business processes by managing risks in conditions of uncertainty (Prodius et al., 2020). These skills are critical for the transformation of scientific discoveries into commercially successful products and services. Their development requires a combination of theoretical knowledge with practical experience, the acquisition of which involves internships in innovative enterprises, participation in startup projects, and training in business incubators.

2. Justification of a comprehensive approach to the investment assessment of human capital in the national innovation system

Human capital investment valuation is a set of methods and tools aimed at quantitatively and qualitatively determining the value of human resources in terms of their potential to generate future income and contribute to the innovative development of the country. Traditional approaches to human capital investment valuation were based mainly on indicators of formal education, work experience and professional qualifications however, modern realities require a comprehensive approach.

The cost approach involves calculating the total investments made in human development throughout their lives, in particular the costs of education at all levels, advanced training and employment of graduates (Nochka, 2022). According to the World Bank, the importance of investments in the education system as the basis for the formation of quality human capital is emphasized, where early investment in preschool and basic education is of particular importance, which provides the highest return in the long term (World Bank Group, 2019). Germany, which invests over 8 thousand euros per year in the education of each student, demonstrates high results in the innovative development of human capital, which indicates the importance of investments in the education system to ensure the country's competitiveness (Dumanskaya, 2021, March 8). The advantage of this approach is the relative simplicity of calculations and the availability of statistical data. However, it does not take into account the effectiveness of investments and individual differences in people's abilities.

The income approach assesses human capital through the discounted value of future income that a person can generate during his or her working life. This refers to the difference in wages between individuals with different levels of education and qualifications, which allows us to assess the return on investment in human development (Nochka, 2022). The difficulty in applying this approach lies in the need to forecast future income and choose the appropriate discount rate.

The market approach is based on the analysis of the impact of market prices on human capital, expressed in wages, bonuses, and the cost of hiring and retaining personnel. This approach demonstrates the real assessment of human capital by employers (Nochka, 2022). However, it can be distorted by labor market imperfections, information asymmetries, and institutional constraints.

In the context of the national innovation system, the qualities of human capital, which are subject to investment assessment according to the actual results reflected by innovation indicators, are of particular importance. These qualities usually include:

effectiveness – the degree of formation of human capital with the replenishment of human resources at enterprises, institutions and organizations in favor of achieving their goals (the number of graduates of higher education institutions);

creative abilities – the ability of human capital to generate new original ideas and make unconventional decisions when solving current

problems (publication activity of scientists, the number of applicants for postgraduate studies);

adaptability – the ability of human capital to inter-sectoral movement in favor of mastering new skills in conditions of rapid technological changes that create the need for constant updating of competencies (the share of specialists with IT specialties) (Petrova & Pereira, 2024).

However, all of these indicators are difficult to quantify using traditional methods, which necessitates the development of special indicators.

Therefore, a comprehensive approach to the investment assessment of human capital in the national innovation system should combine quantitative and qualitative indicators, taking into account the specifics of different categories of employees, the characteristics of innovation processes and the strategic priorities of the country's economic growth.

3. The analysis of the human capital in Ukraine based on traditional and innovative indicators

The analysis results of the state of human capital in Ukraine for the period 2015–2024 revealed contradictory trends that reflect both structural problems of the education system and the labor market, and the impact of external shocks, in particular a full-scale war. The study of traditional indicators allows us to form a comprehensive picture of changes in human capital and identify the main challenges for its further development in the national innovation system (*Table 1*).

Table 1

Traditional indicators of human capital in Ukraine for 2015–2024

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Education expenditure (% of GDP)	5.2	5.8	5.6	5.4	5.8	5.9	6.0	6.1	6.2	6.3
Number of students in higher education institutions (thousand people)	1605	1586	1539	1522	1440	1204	1037	892	758	678
Number of applicants (thousand people)	291	264	245	238	235	224	212	205	246	197
Average salary (UAH)	4195	5183	7104	8865	10497	11591	13543	15181	16784	17487
Unemployment rate (%)	9.1	9.3	9.5	8.8	8.2	9.5	9.9	18.5	17.4	14.3

Source: compiled by the author based on (TSN, 2025, March 19; Ukrstat, 2015–2024b; 2015–2024c; Ministry of Finance, 2022; 2025a; 2025b).

As can be seen from *Table 1*, education spending in Ukraine in 2015 corresponded to the average level of countries with economies in transition. In 2016, this indicator increased slightly, which can be explained by the

partial restoration of budget financing of the education sector after economic stabilization. By 2018, the share decreased slightly, which is explained by competition between different areas of budget spending. From 2019 to the end of 2021, there has been a gradual increase in education spending, which can be associated with the need to support this sector in the context of the COVID-19 pandemic. By the end of the analyzed period, there was a gradual increase, however, this effect is largely explained by the drop in GDP during the martial law period, as a result of which the relative share of spending looks higher without a real increase in their volume. Therefore, the trends in education spending are contradictory, since nominal growth does not guarantee an increase in the quality of education. The results of the analysis of education spending demonstrate a gradual increase in the share of education spending in the GDP structure. However, this growth is insufficient compared to the legally established norm of 7% of GDP, stipulated in Article 78 of the Law of Ukraine "On Education" (2017, September 5). The main factors inhibiting the process of financing education were fiscal constraints related to the need to finance defense, taking into account the general economic instability. The current problem remains the inefficient distribution of educational resources, the lack of a clear system for monitoring the effectiveness of educational programs, and insufficient guidance for the development of human capital among youth.

The decrease in the number of students in higher education institutions from 2015 to 2016–2017 indicates a demographic decline in school graduates with the establishment of the initial stage of labor and educational migration. In 2018–2019, the indicator decreased, which can be considered as a stable trend towards the outflow of young people from the higher education system. By 2021, the indicator had sharply decreased, when online learning due to the COVID-19 pandemic significantly reduced the attractiveness of higher education institutions. By the end of 2023, the war caused a sharp drop in the student contingent due to forced migration and the destruction of infrastructure as a result of hostilities, and in 2024 the negative trend persisted. This situation is critical for the country’s human resources potential, taking into account a more than twofold decrease. Firstly, the demographic crisis that began in 1990 significantly reduced the number of cohorts of traditional student age. Secondly, increasing labor migration led to the departure of a significant part of young people abroad for education and work. Thirdly, military operations and mobilization significantly affected the contingent of male students, which became especially noticeable during 2022–2024.

The number of applicants also gradually decreased in 2015–2019. This can be explained by the strengthening of the demographic decline and the decline in interest in obtaining higher education. By 2021, the number of applicants continued to decline, which may indicate the consequences of the COVID-19 pandemic and the partial transition of young people to work or short-term educational programs. In 2022, the decline in the indicator slowed down, and in 2023 there was a temporary surge due to the adaptation of the admission rules under martial law and deferred demand. However, in 2024

the indicator decreased again, indicating a persistent negative trend, which can be explained by the decrease in attractiveness in certain professions due to the low growth in average wages.

The average wage gradually increased in 2015–2017. This period was characterized by the recovery of the economy after the currency crisis of 2014–2015. Until 2019, the average wage continued to grow, reflecting indexation and economic recovery. In 2020, the growth of the indicator slowed down due to the impact of the COVID-19 pandemic. Until the beginning of 2024, gradual growth is observed. However, this increase was the smallest in a decade, which indicates the impact of the economic recession due to the war. Despite the significance of nominal growth, inflationary processes forced real incomes to grow more slowly. The key factors in this growth were structural changes in the economy, increased labor productivity in certain sectors, especially in the IT industry, and labor shortages. At the same time, the average wage in Ukraine remains significantly lower than European standards and, accordingly, continues to stimulate labor migration, which is also reflected in the unemployment rate in the country.

The unemployment rate increased slightly from 2015 to the end of 2017, but by 2019 the indicator gradually decreased, reflecting a certain recovery of the economy. However, in 2020 it increased, and the main factor of influence was the COVID-19 pandemic. In 2021, the unemployment rate rose, and in 2022 there was a sharp jump due to military operations, mass closure of enterprises, institutions and organizations, and the loss of a significant number of jobs. Later, in 2023, the indicator began to gradually decrease, which is associated with the adaptation of the economy to wartime conditions, the development of remote forms of work, and a decrease in the number of registered unemployed due to population migration and a reduction in the term of social assistance payments, which ultimately led to a decrease in the calculation base. However, structural problems in the labor market still remain unresolved. This, in particular, is the mismatch of qualifications with employer demand, regional disparities and the lack of effective retraining programs.

Therefore, during 2015–2024, Ukraine’s human capital underwent systemic demographic changes, which were influenced by emigration processes, quarantine restrictions and the devastating consequences of the war. On the one hand, the growth of education spending and wage increases reflect a situation where the state is trying to maintain educational and labor potential. On the other hand, the number of students and applicants is decreasing in conditions of high unemployment, which creates significant risks for the reproduction of qualified personnel. All this negatively affects the development of the national innovation system, which requires a continuous influx of specialists to conduct high-quality scientific research, develop new technologies and carry out entrepreneurial activities. Due to the loss of educational and labor resources, Ukraine is noticeably lagging behind in the global competition for knowledge and innovation. This calls into

question the favorable conditions for accelerated modernization of the country's economy, as indicated by trends in changes in quantitative indicators of migration processes (*Table 2*).

Table 2

Migration processes in Ukraine and their impact on human capital in 2015–2024

Indicator, number	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Labor migrants (million people)	1.3	1.5	1.9	2.7	3.2	3.0	2.5	n/d		
Internally displaced persons (million people)	1.6	1.7	1.5	1.4	1.4	1.4	1.5	6.2	8.2	8.0
Repatriates (thousand people)	45	52	68	84	95	32	25	n/d		
Emigrants for permanent residence (thousand people)	21.4	18.1	15.3	13.2	11.3	3.3	2.2	n/d		

Source: compiled by the author based on (Operational Data Portal, 2022–2024; Ukrstat, 2015–2021).

The number of labor migrants from Ukraine in 2015 indicates a significant outflow of labor after the events of 2014 and the beginning of the war in eastern Ukraine. In 2016, the indicator had an imperceptible increase, and in 2017 its value increased further, which was due to the worsening economic situation, rising unemployment, and Ukrainians' search for better employment conditions abroad. The most dramatic increase occurred during 2018–2019, when the number of labor migrants increased by 0.5 million people. Such trends can be explained by the opening of a visa-free regime with the EU for Ukrainians since 2017 and the active involvement of workers in the labor markets of Poland, the Czech Republic, and other EU countries. In 2020 and 2021, due to the COVID-19 pandemic, there was a certain reduction in migration flows, which was due to restrictions on movement and the partial return of migrants' home. Data for 2022–2024 are not available, reflecting the difficulty of recording in wartime conditions, when migration became massive and chaotic. Forced displacement within Ukraine in 2015 was significant, mainly due to active hostilities in eastern Ukraine and the annexation of the Autonomous Republic of Crimea. In 2016, this figure increased slightly, but by the end of 2019 it showed a gradual decline, due to some stabilization of the front line and partial integration of displaced persons into the receiving regions. The situation remained relatively stable until 2021, but in 2022, due to a full-scale invasion, the number of internally displaced persons increased sharply. In 2023, this figure showed a peak value in the entire history of Ukraine's independence and in 2024 remained extremely high. This situation places an unprecedented strain on social infrastructure, regional labor markets, and the education system, leading to a redistribution of human capital within the country and an increase in regional disparities.

The number of labor migrants returning home gradually increased from 2015 to 2019, which may be a consequence of economic stabilization, wage increases, as well as the state's attempts to stimulate the influx of qualified personnel from abroad. However, by the end of 2021, due to the

COVID-19 pandemic and uncertainty in the labor market, this indicator was noticeably decreasing. After 2022, the registration of returned labor migrants to the country became more difficult, as a significant part of the population was forcibly displaced, while labor migration processes lost their regularity. Due to crisis events, the positive trend in the return of the labor force was interrupted. Emigration to a permanent place of residence during 2015–2019 showed a noticeable decrease. Such trends are explained by the gradual improvement of economic conditions and the expansion of opportunities for temporary labor migration, which reduced the need to leave the country. During 2020–2021, due to travel restrictions and the uncertainty of the COVID-19 pandemic, there was a sharp decline in the indicator. After 2022, official statistics are not available. It can be assumed that a full-scale war could have led to an increase in the number of people who went abroad with the intention of staying there for a long time.

Migration processes have become a critical factor influencing Ukraine's human capital. The main drivers of this process were a significant gap in wage levels between Ukraine and EU countries, limited opportunities for professional development within the country, and the gradual simplification of the visa regime with EU countries. The full-scale war radically changed the nature of migration processes, transforming them from predominantly labor to forced displacement. According to the Ministry of Foreign Affairs of Ukraine, as of June 2023, more than 8 million Ukrainians were abroad, which is approximately a fifth of the country's pre-war population (OPORA, 2023, July 5). Under such conditions, the impact on the national innovation system is significantly negative. After all, the outflow of labor migrants and the low level of return reduce the human resource base for the development of innovatively active enterprises, institutions, and organizations. At the same time, the increase in the number of internally displaced persons additionally burdens the socio-economic infrastructure, which diverts resources from investments in innovation. All this makes it impossible to plan long-term personnel policy in the fields of education, science, and IT, limiting the capabilities of Ukraine's human capital in building a competitive national innovation system, as indicated by trends in innovation indicators (*Table 3*).

Table 3

Innovative indicators of Ukraine's human capital for 2015–2024

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Graduates of higher education institutions (thousand people)	318	267	249	236	221	198	172	165	158	145
Share of IT specialties (%)	8.2	9.1	10.3	11.8	13.2	14.5	16.1	17.8	18.9	19.7
Number of postgraduate students (thousand people)	28.5	25.8	22.4	19.2	16.8	14.2	12.1	10.5	9.8	10.1
Publications in Scopus (thousand people)	9.2	10.1	10.8	11.2	11.9	10.2	9.8	8.9	9.1	9.3

Source: compiled by the author based on (SJR, 2015–2024; Ukrstat, 2015–2024a; 2015–2024b).

The decrease in the number of graduates of higher education institutions in 2016 compared to 2015 can be explained by the demographic decline and the gradual reduction in the number of students in previous years. Until 2018, the indicator slowly continued to decline, reflecting structural problems in the education system and a decrease in the demand of young people for long-term educational trajectories. In 2019–2020, the reduction in graduation was due to the COVID-19 pandemic, which forced higher education institutions to switch to online learning. From 2021 and until the end of the analyzed period, the indicator decreased by more than half compared to 2015. This trend reflects a combination of demographic processes, migration losses and military upheavals, which significantly reduce the potential for the reproduction of a qualified workforce. Among graduates, the share of IT specialties showed the opposite trend, demonstrating steady growth. Such dynamics reflect the global demand for digital professions and the adaptation of Ukrainian universities to the needs of the labor market. This trend also indicates an active structural transformation of the educational field, where even with a reduction in the total number of students and graduates, digital specialties occupy an increasingly important place, reflecting the economy's orientation towards digitalization, which is also the orientation of degree holders. The number of postgraduate students gradually decreased from 2015 to the end of 2017, which was due to a decrease in funding for science and a weak motivation of young specialists to remain in this field. From 2018 to the end of 2021, this indicator continued to decline: restrictions due to the COVID-19 pandemic, a decline in international academic exchanges, and low employment prospects in the field of science caused a significant decline. Its further decline until the end of 2023 reflected the mass emigration of young scientists during the period of martial law and the destruction of scientific infrastructure. Only in 2024 is there a slight recovery. This may be due to the support of international funds and the preservation of individual research centers. Overall, the number of postgraduate students has decreased almost threefold over the decade, which critically limits the human resource pool for science and innovation.

Trends in the number of scientific publications in the Scopus database reflect ambiguous processes. From 2015 to 2018, their number gradually increased due to the active integration of Ukrainian scientists into international research networks and the expansion of requirements for publication activity. In 2019, the number of publications reached a decade-long peak. However, in 2020–2021, the indicator dropped significantly, which is explained by the restriction of the mobility of scientists due to the COVID-19 pandemic and the decrease in funding for the field of science. In 2022, the number of publications decreased further due to the destructive impact of the war, but in 2023, a small recovery of science was observed, which continued in 2024, accordingly increasing this indicator. This indicates the resilience of individual scientific groups and their ability to maintain international communication even in times of crisis.

Therefore, the main problems of human capital development in Ukraine include the lack of funding for education and science, mass emigration of qualified personnel, mismatch of educational programs with labor market needs, as well as weak integration between the education, science, and IT sectors. The war added new challenges, including the destruction of educational and scientific infrastructure, psychological traumatization of applicants, and the need for the latter to adapt to the distance learning system in conditions of limited access to ICT. The prospects for the restoration and development of human capital in Ukraine in the post-war period require increased investment in education and science in favor of forming effective mechanisms for the return of migrants, modernization of educational programs in accordance with the needs of the modern economy, and the development of an innovative ecosystem. And here it is critically important to ensure the quality of education at all levels, develop a system of continuous learning, and create incentives for retaining talent in Ukraine.

4. Challenges and perspectives for human capital development in Ukraine

Martial law in Ukraine has created both serious obstacles and new opportunities for the development of human capital, the main challenges of which are associated with the physical destruction of educational and scientific infrastructure, the loss of part of the population due to military operations and forced migration, as well as the need for rapid adaptation in the labor market to new conditions for the functioning of enterprises, institutions and organizations. At the same time, the full-scale war has become a powerful stimulus for innovation processes, accelerating the implementation of new digital technologies and contributing to the intensification of international cooperation in the field of education and science.

The digitalization of education has become one of the most significant trends in the development of human capital under martial law. The mass transition to distance learning, the development of online platforms, and the use of modern educational technologies have radically changed approaches to the organization of the educational process. These changes are long-term in nature and create the basis for the modernization of the entire education system (Ministry of Education and Science of Ukraine, 2023, August 22).

The United Nations Development Programme actively supports initiatives aimed at strengthening human capital in Ukraine, where international support for education and science has opened up new opportunities. Academic mobility programmes, grants for Ukrainian researchers and technical assistance to educational institutions contribute to the deeper integration of Ukrainian education into the European space and to improving its quality (UNDP Ukraine, 2023, October 27).

The development of the IT industry demonstrates the potential of the Ukrainian economy in promoting high technologies and creating opportunities for creating high-paying jobs. Ukrainian IT companies successfully compete in the global market, ensuring the export of services and the creation of added

value. The accumulated experience can be extended to other sectors of the knowledge economy. Under such conditions, state investment policy should be oriented towards the prospect of innovative development of human capital, focusing on early and continuous investments in the education sector, in particular in the STEM education subsector. These priority areas include training in scientific research (Science) and modernization of educational institutions with an emphasis on IT (Technology), engineering and mathematics. In this context, specialists should constantly improve their level of knowledge by obtaining dual education within the framework of continuous retraining of adults and completing paid internships.

Therefore, the return and retention of highly qualified personnel should be aimed at reducing the transaction costs of mobility and accelerating professional integration by combining fiscal incentives for talented individuals returning from abroad (temporary tax holidays/credits tied to actual employment and value-added creation) with targeted support at the return/relocation stage (grants, housing subsidies). Such incentives should include accelerating the nostrification of higher education documents, simplifying visa/migration procedures for submitting documents for employment of researchers and engineers and their consideration in a shortened period of time through the "single window" service. All this will allow combining work in Ukraine with participation in international projects in flexible employment formats (hybrid on-site/remote models) under diaspora visit programs (education – business – science) aimed at exchanging knowledge in the context of sustainable institutional interaction. Strengthening relevant partnerships provides structured career growth for young scientists, including through their PhD theses and further scientific activities in collaboration with enterprises, institutions and organizations engaged in innovation. Such incentives should be accompanied by transparent selection criteria, KPI contracts (employment in the specialty, participation in scientific/innovative projects, commercialization of results) and performance monitoring, which will ensure their effectiveness in the context of trust from stakeholders (Trade Union of Education and Science Workers of Ukraine, 2022, February 8).

Alignment of investment support for the education sector with the needs for the development of science and IT industries can be ensured by establishing a National Skills Observatory, which would regularly forecast demand for these industries based on the formation of a competency map; establishing sectoral councils on curricula; defining KPIs for HEIs (employment by specialty, employer vouchers for (re)training) and creating inter-university hubs on artificial intelligence, cybersecurity, robotics, and bioinformatics. At the same time, strengthening the development of technology transfer infrastructure and the startup ecosystem requires the professionalization of technical and technological offices (TTO), which would ensure transparency of investment policy by the state within the framework of providing grant support to scientific institutions to verify the viability of an innovative

idea/project (Proof-of-Concept) and financial support to small and medium-sized businesses, venture funds, a network of technology parks/centers of shared access to laboratories in the direction of their implementation of internal investment programs for the development of innovations.

This support can be consolidated in a special fund with funds from individuals and legal entities, international partners and from state/local budgets on co-financing terms, where the supervisory board with the participation of the state, business, higher education institutions and the public will be responsible for managing financial resources. The distribution of these funds should be carried out through open competitions with KPI-contracts based on the results of an audit of enterprises, institutions and organizations (employment by specialty, number of inventions, investment potential, patents and/or licenses, high-tech exports). The expected effect should be an increase in employment and a decrease in structural unemployment, which will accelerate the commercialization of knowledge in favor of expanding the base of sources of investment support for the post-war reconstruction of Ukraine (Institute of Economic Research, 2024, December 17).

Conclusions

The combination of traditional indicators based on cost, income and market approaches to the investment assessment of human capital with innovative indicators of performance, creative abilities and adaptability of a person in the system "education – labor market – science" helps to more accurately determine the feasibility of investments in the development of the national innovation system.

In Ukraine, despite the gradual increase in the share of education expenditures in GDP and the intensification of specialists' training in IT sphere, there are persistent demographic and migration losses, when the contingent of higher education institutions and postgraduate studies is noticeably reduced. Peak unemployment in the first years of the war and incomplete recovery of employment, which affects the cyclical fluctuations in the publication activity of scientists, form critical limitations on the reproduction of innovative personnel, significantly weakening the potential for commercialization of knowledge. Therefore, an integrated assessment of human capital in combination with traditional indicators with innovative ones helps to better predict the efficiency of investment allocation and the effectiveness of innovations. According to the results of the analysis of innovation indicators, a structural shift was revealed, when, against the background of a general narrowing of the educational base, the share of IT specialties increased noticeably. However, the official statistics for 2022–2024 lack data on labor migrants, repatriates, and emigrants for permanent residence, which complicates a full-fledged investment assessment of human capital using a comprehensive approach.

The above confirms the need to highlight all indicators as factors of mutual influence of educational institutions, business companies and scientific institutions in the system "education – labor market – science", which reflects the effectiveness of the functioning of the national innovation system in conditions of shocks and uncertainty. Here it is important to justify the priority of early and continuous investments in the education sector using the tools of returning from abroad and/or retaining highly qualified personnel in the country within the framework of harmonizing educational programs with the needs of the science and IT sectors in the development of technology transfer infrastructure and startup ecosystem, including through a special investment fund with KPI contracts. The formation of an innovation ecosystem in Ukraine requires coordination of efforts of the state, business, educational institutions and scientific institutions, which contributes to the creation of technology parks, business incubators, technology transfer centers for the benefit of commercialization of scientific developments and the development of innovative entrepreneurship, where support for young researchers and startups in the IT sector is of particular importance.

In general, the results obtained confirm the hypothesis put forward: the integration of cost, revenue and market approaches with a system of innovation indicators (efficiency, creative abilities, adaptability) helps to more accurately diagnose the state of the national innovation system at the expense of better substantiation of investment decisions than using each group of indicators separately. Empirically, this is manifested in a combination of contradictory trends: the share of education expenditures in GDP is growing, while the contingent of higher education institutions and postgraduate studies is decreasing in conditions of unstable trends in scientific publications, the number of higher education graduates is significantly shifting towards IT specialties against the background of peak unemployment under the influence of war and migration. Together, such shifts make it possible to more accurately identify "bottlenecks" in the reproduction of scientific personnel and specialists in innovation activities, strengthening the argument in favor of making early and continuous investments (including incentives for the return/retention of talents) in the development of technology transfer infrastructure and the startup ecosystem. At the same time, the lack of data in official statistics on population migration for 2022–2024 leaves room for clarification.

Further research is proposed to be devoted to assessing the effectiveness of investing in innovative human capital development in each region in an industry comparison using a single model (formula) of a comprehensive approach to such an assessment, based on individual data of graduates and employers. Modeling various reconstruction options based on the principle of random scenarios (baseline, optimistic, pessimistic) in the context of the dynamics of traditional and innovative human capital indicators will help identify cause-and-effect relationships between them, the influencing factors of which are related precisely to the effectiveness of investment policy of both the state and society.

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